ACCESSIBILITY TO HEALTHCARE VIA PUBLIC TRANSIT: A CASE STUDY OF THE ATLANTA METROPOLITAN AREA

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ACCESSIBILITY TO HEALTHCARE VIA PUBLIC TRANSIT: A CASE STUDY OF THE ATLANTA METROPOLITAN AREA

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LIST OF SYMBOLS AND ABBREVIATIONS

MARTA	Metropolitan Atlanta Rapid Transit Authority
GIS	Geographic information system
ACS	American Community Survey
APTA	American Public Transit Association
GTFS	Google Transit Feed Specification
SDOH	Social determinants of health

SUMMARY

Access to transportation is one of the major social determinants of health (SDOH). Environmental conditions where people are born, live, learn, work, play, worship, and age have an impact on a variety of health, functioning, and quality-of-life outcomes and risks; these conditions are known as social determinants of health (American Hospital Association, 2023). For households without cars, public transportation is essential for accessing healthcare (Liu et al., 2022). Adequate public transportation can help ensure patients are able to attend their healthcare appointments as scheduled and decrease the number of missed appointments. On the other hand, a lack of public transit could disrupt health outcomes by leading to delayed diagnoses or exacerbating existing conditions (American Hospital Association, 2023). Due to varying socioeconomic factors such as race, ethnicity, and car ridership, different households have unequal access to healthcare, so transit is their only way of reaching healthcare facilities (Liu et al., 2022). This study will investigate the accessibility of healthcare in the Atlanta Metropolitan Area via MARTA bus routes to understand how accessible healthcare is for transit-dependent individuals. Transit dependency constitutes individuals who have limited access to other modes of transportation, such as those above 65, below 18, and people with disabilities (American Public Transit Association, 2017). The goal of this study is to identify the census tracts in the study area that have limited access to healthcare facilities via transit, especially for transit-dependent people. The study will focus on the MARTA bus routes rather than the MARTA rail, as there is greater reach through the bus network.

CHAPTER 1: INTRODUCTION

A community's ability to maintain health depends on the availability of appropriate and dependable transportation services, as it affects many elements of an individual's life. The ability to obtain health care services might be impacted by transportation-related concerns. These problems could lead to more expensive medical bills, missing or postponed doctor's appointments, and generally worse health outcomes (Smith & Yang, 2021.). Additionally, transportation can be a tool for wellness. Health can be improved by creating bike lanes, bike-share programs, walkable communities, inexpensive and suitable transportation options, and other healthful transit options. According to the American Hospital Association, Because of transportation problems, 3.6 million Americans do not receive medical care annually. Lack of car access, poor infrastructure, long travel times and distances to necessary services, high transportation expenses, and unfavorable travel-related policies are some of the transportation-related problems that they face to get access to healthcare. Millions of Americans suffer from transportation disadvantages as a result of their incapacity to finance or supply their own transportation. For a variety of reasons, including living in a remote place, being too impoverished, being disabled, or not being able to drive, these people are unable to afford buses or taxis. This means that this group, which is disproportionately made up of the elderly, the poor, and the disabled, depends on other people to get jobs, healthcare, education, and shopping. Fewer people may receive routine and other non-emergency medical care as a result of this dependency, which could be detrimental to their health. People who would benefit from screening, prevention, and health promotion, as well as those who are at risk for multiple diseases, such as diabetes, asthma, and heart failure, are primarily affected by this possibility. Lack of access to care can cause regular conditions to worsen to the point where emergency care is needed. One such instance is when a serious asthma attack is brought on by poorly managed asthma, which is common in children living in inner cities. Therefore, by improving access to healthcare for those who are less fortunate in terms of transportation, lowering the overall cost of health care may be able to offset the incremental increase in transportation costs.

A person who exclusively depends on public transportation for local mobility access is referred to as a "transit dependent." This means the transit dependent person will not have any other modes of vehicles available to them. When people have a car, they will naturally use their car to take a trip to their preferred healthcare facility. But when patients do not have a private vehicle, their other option would be to use the public transit but if the public transit is not connected to all the locations where healthcare facilities are located it will limit the choices for the transit dependent population. So, any negative impact on the transit service or a lack of service in the transit system will affect the transit dependent people the most.

This thesis is a case study of the Healthcare accessibility via public transit in the Atlanta Metropolitan area. The study will first analysis the characteristics of the transit dependent population in the

Atlanta Metropolitan Area to investigate if there is a difference in the census tracts that have MARTA bus routes vs the ones that do not. This will help to find the transit need in the study area. Next the study analyzes the travel time from different MARTA bus stops to the existing healthcare facilities. This will help the policy makers and transportation professionals to understand the efficiency of the existing transit system and to plan for the future accordingly.

CHAPTER 2: BACKGROUND

2.1 Literature Review:

According to Kolak et al. (2020) and NEJM Catalyst (2017), one of the main socioeconomic determinants of health is access to healthcare. The availability of transportation to medical facilities, hospitals, lab testing centers, and other sites where people can receive care is a crucial prerequisite for obtaining health services. Public transportation is a vital means of accessing health services in many urbanized areas, especially for populations for which driving a car is either impractical (such as those with severe visual impairments, uncontrolled epilepsy, or diabetes without hypoglycemic awareness) or too expensive (such as those from lower socioeconomic status (Boisjoly et al., 2020; Wallace et al., 2005). These traits typically indicate a person who is suffering poorer social involvement as a result of not having access to transportation—a problem known as "transport related social exclusion" (Lucas, 2012).

According to recent studies, relying on public transportation can make one more vulnerable to a variety of outside factors. Scholars have traditionally associated transit dependency with income and the presence of disabilities (Church, Frost, and Sullivan 2000; Garrett and Taylor 1999; Litman 2006; Thompson et al. 2012). Therefore, even while living without a car has obvious health and environmental benefits, we still need to critically analyze how disadvantaged communities use public transportation systems that are often excluded due to design decisions that prioritize cars. Transit-dependent riders who depend on public transportation to meet various demands on a daily basis are at a disadvantage when public infrastructures are modified in service of an able-bodied worker who travels a direct route from home to work and back (Ribero, Magrinya, and Orrico Filho 2014). Economic booms have been observed to promote the promotion of unsustainable means of travel, such as vehicles, over further investment in public transportation networks (Ribero, Magrinya, and Orrico Filho 2014). This suggests that hegemonic preconceptions about patterns of mobility may be further perpetuated during these times. Because of this, public transportation systems around the world still differ significantly in terms of service, affordability, and accessibility. These differences can further marginalize and exclude certain groups of people from society, such as women, minorities, and low-income riders, who find it difficult to use services that do not take into account their unique mobility patterns (Aldred 2014; Butcher 2011; Gaffron, Hines, and Mitchell 2001; Lucas and Currie 2012; Sheller and Urry 2000).

Classical conceptualizations define accessibility as the ease with which any land use activity can be reached from a location using a specific transport system (Kwan& Weber, 2003; Lau & Chiu, 2003; Miller, 2005; Papa & Bertolini, 2015). From the various definitions and useful metrics of accessibility, Geurs and Van Wee (2004) distinguished four categories of constituents. These components include transportation (i.e., the infrastructure available for covering the distance between origin and destination using a specific transport mode); land use (i.e., the quantity, quality, and spatial distribution of activity opportunities and individual needs); temporal constraints (i.e., the availability of opportunities at different times of the day); and people-related components (e.g., individual physical condition, availability of adequate travel modes, monetarily and temporally allocated travel budgets). This study will only focus on transportation accessibility, to be more specific, it will focus on transit accessibility.

Based on the literature review, the following term have been defined in the following manner for the purpose of the study:

- **Golden hour:** It is the term often used in trauma or emergency care to suggest that an injured or sick person must receive definitive treatment within the first 60 minutes from the time of injury or appearance of symptoms (Lerner & Moscati, 2001)
- **Accessibility:** The ease with which any land use activity can be reached from a location using a specific transport system (Kwan & Weber, 2003)
- **Spatial accessibility:** The ease with which any land use activity can be physically reached from a location using a specific transport system (Guagliardo, 2004)
- **Public transit:** forms of transportation, run by the regional or local government, open to the public (CDC, 2021) In this study, only the MARTA bus routes will be discussed as the public transit service.
- **Healthcare facility:** A health facility is, in general, any location where healthcare is provided (Guagliardo, 2004) In this study, only hospitals and clinics are being discussed as healthcare facilities.
- **Service area:** The area surrounding the healthcare facility whose residents receive most of their hospitalizations from the hospitals in that area (Gresenz et al., 2004)
- **Clinic:** A clinic is generally a smaller facility than a hospital where patients are less sick and do not stay overnight (Gresenz et al., 2004)
- **Hospital:** Hospitals are licensed institutions whose primary function is to provide diagnostic and therapeutic patient services for medical conditions (Gresenz et al., 2004)
- **Disadvantaged area:** Based on different attributes such as climate change, clean energy and energy efficiency, clean transit, affordable and sustainable housing etc. it is decided if the community is disadvantaged or not (Office of Environmental Management, 2023; USDOT, 2023).

- **Transit dependent & vulnerable group of people:** People who are unable to drive (for example, population without access to personal vehicles (such as low-income population), children, individuals with disabilities, and older adults) (APTA, 2019)

2.2 Study Area Description: MARTA Bus Service

Atlanta's integrated bus, rail, and streetcar transit system is called MARTA. There are more than 1,000 miles of bus routes throughout Atlanta, 48 miles of rail, and 2.7 miles of circular streetcar tracks. On the weekdays the MARTA bus runs from 5 a.m. to 1:30 a.m. and on the weekends and Holidays, it runs from 5 a.m. to 12:30 a.m. Some bus schedules vary depending on the neighborhood. Fulton, Clayton, and DeKalb are the only counties in the Atlanta Metropolitan Area that have MARTA bus service (MARTA, 2023).

MARTA can be a great way to provide a service for people who need regular visits to healthcare facilities, especially for elderly people and people who cannot drive. MARTA has reduced emissions by 95% in 347 of its buses by using compressed natural gas. More than 550 MARTA buses provide service along 1,439 miles of road on 101 routes (MARTA, 2023).

Figure 2.2.1 shows the number of riders for MARTA. Millions of people use the MARTA bus service so analyzing the MARTA accessibility to healthcare facilities is a good way to check the accessibility to healthcare overall.

Figure 2.2.1: MARTA ridership (Source: MARTA website)

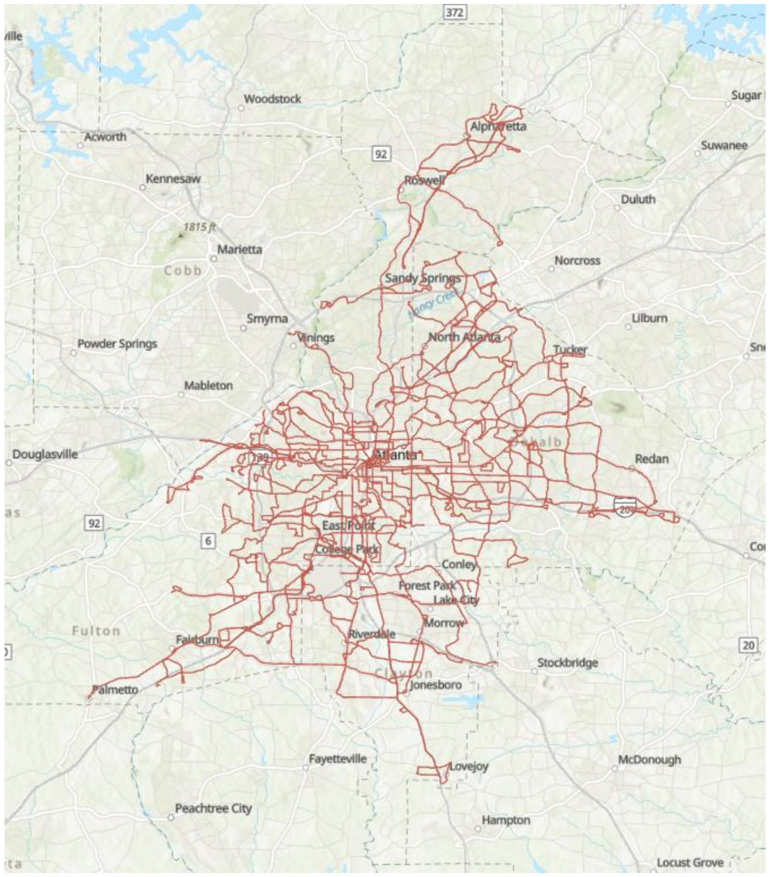

Figure 2.2.2: Existing MARTA bus routes

2.3 Study Area Description: Atlanta Metropolitan Area:

Table 2.3.1: Population and density of the counties with MARTA bus service			
County	**Density**	**Population**	**Area**
Clayton	2,073.87	296,564	143 sq mi
Dekalb	2,846.34	762,820	268 sq mi
Fulton	2,031.44	1,074,634	529 sq mi
Total	2270.23	2,134,018	940 sq mi

There are a total of 22 counties in the study area and three of them (Clayton, DeKalb, Fulton) have MARTA bus service. The population density of the counties with the MARTA Bus service is much higher than the counties that do not have the MARTA Bus service. But some of the counties have similar population density such as Cobb, Forsyth & Gwinnett Counties. These Counties are located close to the MARTA Bus stops so if the MARTA Bus services need to be expanded then it will be very easy to prepare route plans and build new stations. But to understand more about the vulnerable and transit-dependent population of this area relevant data from the American Community Survey were collected.

Table 2.3.2: Population of the Counties without MARTA bus service in the study area			
County	**Density**	**Population**	**Area**
Barrow	551.23	89,299	162 sq mi
Bartow	245.25	112,816	460 sq mi
Butts	142.51	26,649	187 sq mi
Carroll	249.68	124,592	499 sq mi
Cherokee	663.39	281,278	424 sq mi
Cobb	2,270.45	771,952	340 sq mi
Coweta	345.11	152,882	443 sq mi
Dawson	142.83	30,138	211 sq mi
Douglas	740.28	147,316	199 sq mi
Fayette	619.44	122,030	197 sq mi
Forsyth	1,182.46	267,237	226 sq mi
Gwinnett	2,252.55	975,353	433 sq mi
Haralson	111.12	31,337	282 sq mi
Heard	39.61	11,725	296 sq mi
Henry	768.93	248,364	323 sq mi
Jasper	43.11	15,951	370 sq mi
Lamar	105.23	19,467	185 sq mi
Meriwether	41.44	20,845	503 sq mi
Morgan	60.09	21,031	350 sq mi
Newton	426.16	117,621	276 sq mi
Paulding	568.22	178,421	314 sq mi
Pickens	150.11	34,826	232 sq mi
Pike County	91.70	19,990	218 sq mi
Rockdale	725.07	94,984	131 sq mi
Spalding	348.08	68,919	198 sq mi
Walton	313.27	103,065	329 sq mi
Total	524.9	4,088,088	7788 sq mi

People who are "transit dependent" are defined as "any persons who live in a household with no p rivate vehicle available" by the Federal Transit Administration (FTA) of the United States (2013).
The following criteria must be met for a person to be considered transit dependent: (1) they must not have access to private transportation; (2) they must be over 65; (3) they must be under 18; and (4) they must b e below the poverty or median income levels as determined by the U.S. Census Bureau (FTA 2013). To understand more about the transit dependent population in Atlanta Metropolitan Area the relevant economic and demographic characteristics of the counties in the metropolitan area were analyzed.

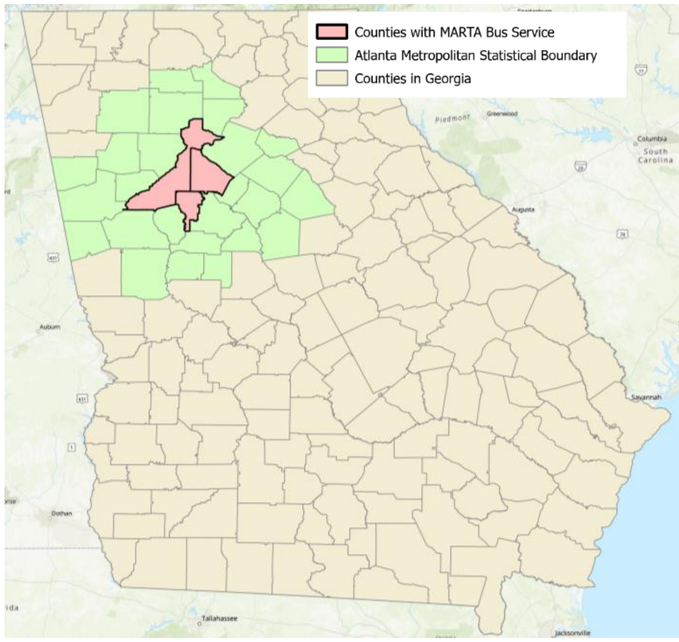

Figure 2.3.1: Location of the study area

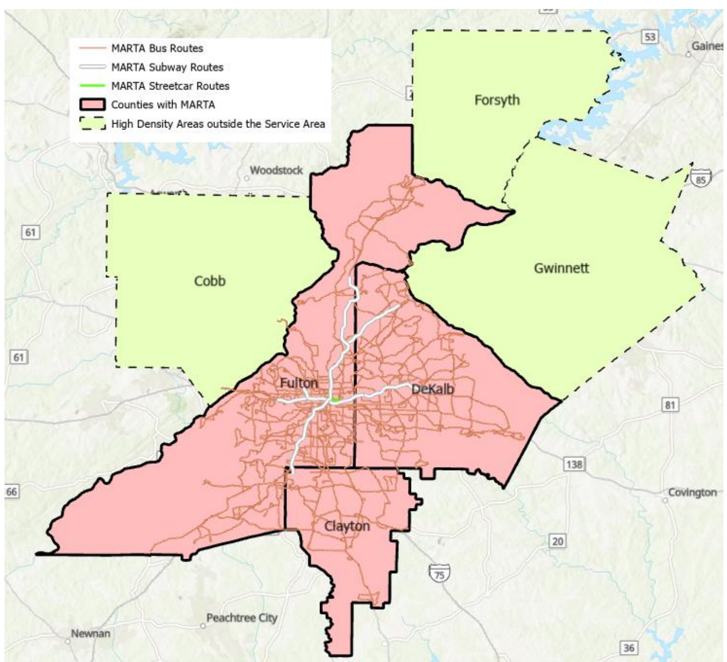

Figure 2.3.2: Location of the counties with high population density in the Atlanta metropolitan area

CHAPTER 3: METHODOLOGY

To complete this study, the Python programming language, STATA statistical software, and ArcGIS Pro GIS software were used. There are several types of accessibility, but the study will only investigate the spatial accessibility for the MARTA bus stops. The following steps will describe the detailed process of completing the study:

Step 1 - Background Study: To understand the existing Transit services and healthcare facilities in the Atlanta Metropolitan Region a thorough background study was done. Through desktop study relevant papers (papers on transit accessibility, healthcare accessibility etc.) were studied to collect information on the healthcare and transit service. The background study was necessary to prepare the goals and objectives of the study and to prepare the methodology.

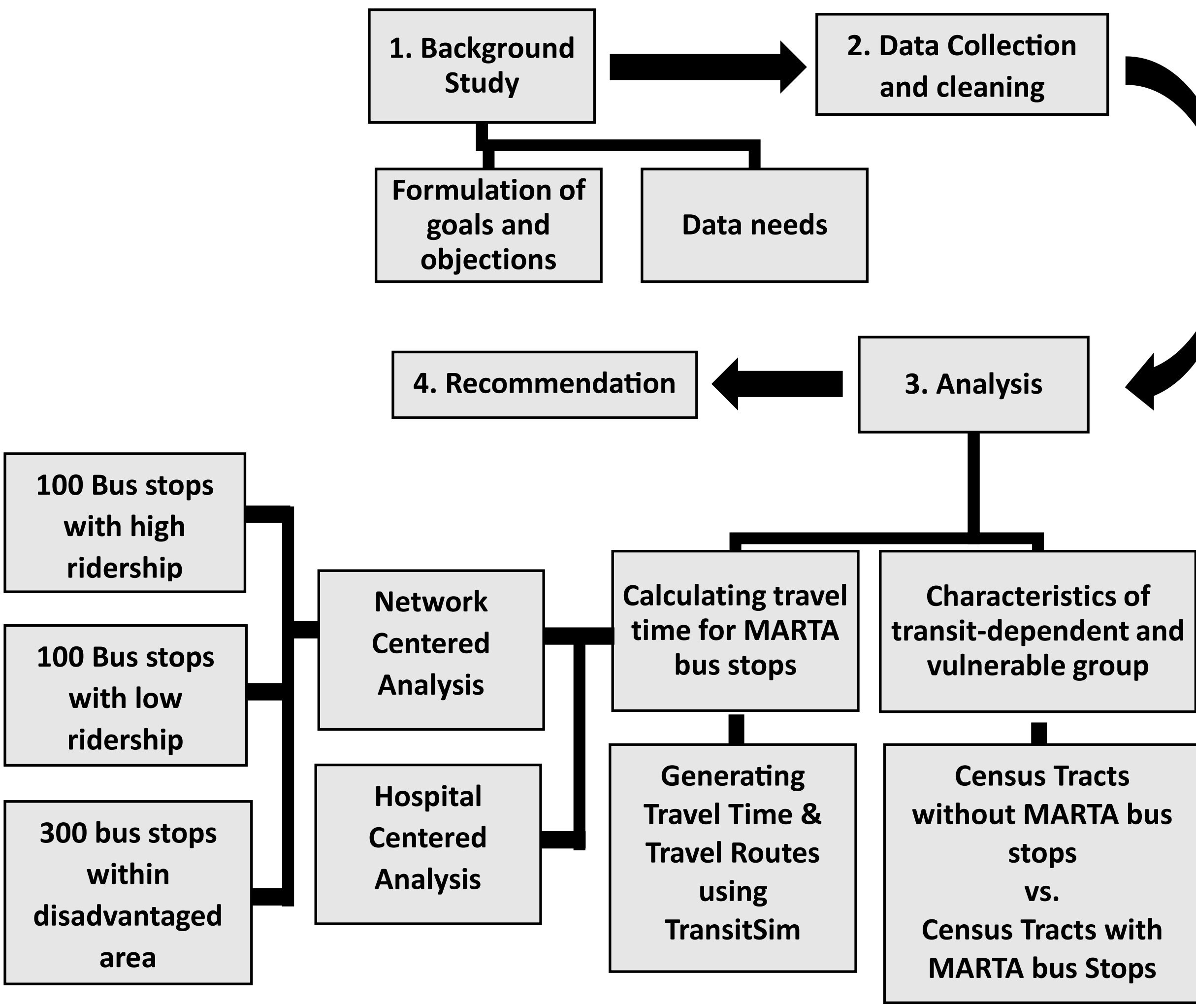

Figure 3.1: Methodology steps

Step 1.1 - Identifying Study Area & Data Needs: MARTA is the main provider of the public transit services in the state of Georgia. The study will calculate the average travel time from the MARTA bus stops to the existing healthcare facilities in the Metropolitan Area. Another objective of the study is to understand if there are any socio-economic differences between the census tracts with the MARTA bus service and without the MARTA bus service. There are three counties (Fulton, Clayton, and DeKalb) among the 29 counties in the state of Georgia that have MARTA bus service. The counties without MARTA bus service (such as Cobb, Gwinnett) might have similar transit-dependent characteristics (such as density, income, Gini index, elderly population) as the counties with MARTA service. So, it would be interesting to compare these counties to see whether the other counties have similar demand for bus service as the counties with MARTA bus service. Another objective of the study is to calculate the average travel time to each of the healthcare services from all the identified bus stops inside the census tracts which are considered disadvantaged according to the Justice40 analysis. To complete these calculations a data list was prepared that would be needed for the calculations.

Step 1.2 - Objectives of the Study: The objectives of the study are as follows –

- Calculating average Travel time to reach the healthcare services via MARTA bus routes.
- Analyzing the characteristics of the transit dependent and vulnerable group of people in the study area to identify where more MARTA bus routes might be needed to improve access to healthcare services.

Step 2 - Data Collection & Cleaning: Based on the background study the following data were collected for the calculation of the study -

- **MARTA GTFS Data:** The General Transit Feed Specification (GTFS) specifies a common format for public transportation schedules and related geographic data. It is also referred to as GTFS static or static transit to distinguish it from the GTFS real-time extension. GTFS "feeds" enable the publication of transit data by public transportation agencies, which can be helpful for researchers and policymakers to get a better understanding of the public transit services in a region (Goggle Transit Official Website, 2023).

  MARTA GTFS data was collected from the MARTA official website. These files contain the MARTA bus stops' location details such as latitude, longitude, wheelchair accessibility, stop id, stop name etc. This information was used as the input to run the TransitSim simulation in python environment.
- **MARTA Bus Ridership Data:** MARTA bus ridership data for the year 2021 was collected from MARTA. This data was used to identify the most used MARTA bus routes in the selected census tracts.

- **Healthcare Location Information:** The Healthcare locations were collected from the OpenStreetMap (OSM) website as a GIS shapefile. The locations were imported in the ArcGIS Pro software and any inaccurate data were deleted to make sure the healthcare locations were accurate. A total of 70 emergency and healthcare locations were found after cleaning the collected data. The Healthcare facilities that are located outside the service areas of the MARTA bus stops were removed during cleaning. These locations were used as the origin of the TransitSim model. Among the destinations, 56 % are clinics and the rest are hospitals. Clinics generally provide non-emergency outpatient care that's routine or preventive. Even though hospitals can provide outpatient services, they focus more on providing inpatient care. Hospitals are typically visited for specialist care, surgery, or for more serious, life-threatening conditions. The study will do an overall geographic accessibility analysis for all the healthcare facilities to investigate how accessible is the MARTA bus route network for all the healthcare facilities. The study will also do an accessibility analysis for each of the facilities to investigate how accessible these facilities are with respect to their service area.
- **American Community Survey (ACS) Data:** Demographic and socio-economic data was collected from the ACS website to understand the more about the characteristics of the study area. In a study done by Linovski et al. (2022), the authors used similar data to understand if there is a significant difference in the census tracts that are being served by public transit vs the census tracts that are not being served by public transit. Gini Index, income, unemployment, and population data were collected from ACS to investigate if there are any major differences in these areas between the census tracts with and without public transit within the study area. Population below 18, Population above 65, disabled population data, people with limited English language knowledge and minority population are described as vulnerable and transit dependent by the American Public Transit Association (APTA) and other transit equity studies have found similar results (Syed et al., 2013; Wolfe et al., 2020). These data were collected from ACS to examine if there is any difference between census tracts that does and does not have public transit.
- **Justice40 Data:** The Justice40 data was collected to identify the disadvantaged census tract in the Atlanta Metropolitan Area. The Justice40 Initiative is a federal level government effort to deliver at least 40 percent of the overall benefits from certain federal investments to disadvantaged communities. A community qualifies as “disadvantaged” if the census tract is above the threshold for one or more environmental or climate indicators and the tract is above the threshold for the socioeconomic indicators. Based on different attributes such as climate change, clean energy and energy efficiency, clean transit, affordable and sustainable housing etc. it is decided if the community is disadvantaged or not (Office of Environmental Management, 2023; USDOT, 2023).

Step 3 – Analysis: The analysis for the study was done in two sections. For the first section only, statistical calculation was done and for the second section TransitSim simulation model was used.

Step 3.1 - Characteristics of transit-dependent and vulnerable group: The study area was first separated into two areas: the census tracts with MARTA bus service and the census tracts without MARTA bus service. The data collected from ACS was used to identify transit dependency for each census tracts. This was done to identify whether there are people outside the MARTA service area who are in need of the transit service.

- **Test of Normality:** STATA Statistical software was used to check the normality of the data.
- **Test of Mean:** A nonparametric test, Mann-Whitney U test was used to calculate the difference in mean.

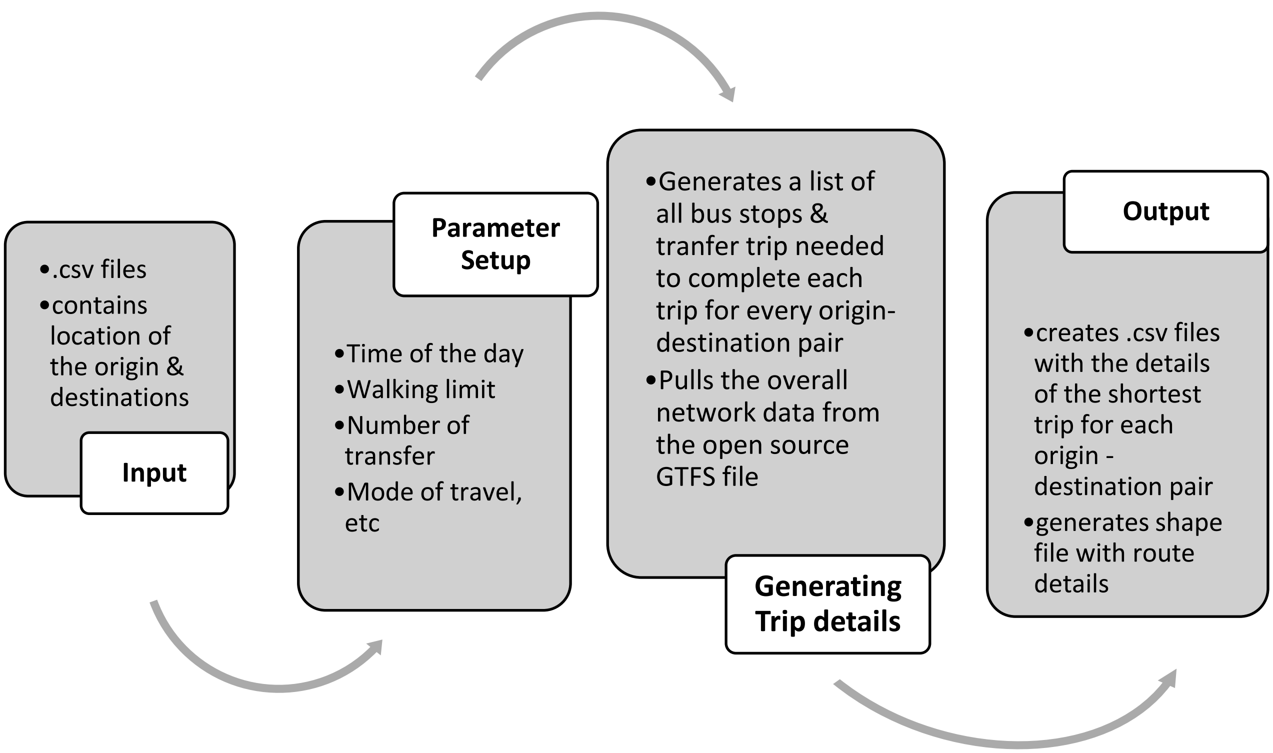

Figure 3.2: Breakdown of the modules used in the TransitSim analysis

Step - 3.2 Calculating travel time for MARTA bus stops: The calculation of the travel time was done in two sections. To understand the travel time of the overall bus network first network centered travel time were calculated. Next, to understand the accessibility of the hospitals separately some calculations were done focused on one destination.

Step - 3.2.1 Setting Up TransitSim Script: TransitSim is a member of the TransportSim multi-modal travel path-finding models family developed by Huiying ("Fizzy") Fan, Hanyan ("Ann") Li, Diyi Liu, Dr. Angshuman Guin and Dr. Randall Guensler; the researchers of Georgia Tec. Other members of the family include RoadwaySim, SidewalkSim, BikewaySim, and CarpoolSim. TransitSim is a link-by-link transit path-finding model that generates the shortest paths for each O-D trip based on the open-source transit network GTFS data, park and ride information, and a given or approximated sidewalk network.

For this study, the TransitSim 4.0 version was used. To test the TransitSim a small number of origins and destinations were selected.

	riding	waiting	walking	boarding/alighting	ori	dest	healthcare_type	emergency	total_time
0	51.950000	35.000000	0.111429	4.0	EAST POINT STATION	Emory University Hospital Midtown	hospital	yes	91.061429
1	51.950000	35.000000	0.111429	4.0	EAST POINT STATION	Emory University Hospital Midtown	hospital	yes	91.061429
2	51.950000	35.000000	0.111429	4.0	EAST POINT STATION	Emory University Hospital Midtown	hospital	yes	91.061429
3	51.950000	35.000000	0.111429	4.0	EAST POINT STATION	Emory University Hospital Midtown	hospital	yes	91.061429
4	51.950000	35.000000	0.111429	4.0	EAST POINT STATION	Emory University Hospital Midtown	hospital	yes	91.061429
...	...	...	...	...	...	...	...	...	...
54200508	NaN	NaN	0.000000	0.0	NaN	NaN	NaN	NaN	NaN
54200509	55.666667	95.033333	0.000000	0.0	NaN	NaN	NaN	NaN	150.700000
54200510	42.683333	38.817326	3.945091	8.0	NaN	NaN	NaN	NaN	93.445750
54200511	78.816667	71.922641	1.094026	12.0	NaN	NaN	NaN	NaN	163.833333
54200512	23.633333	86.816667	1.196149	6.0	NaN	NaN	NaN	NaN	117.646149

Figure 3.3: A Screenshot of the analysis from the initial test run

Figure 4.3 shows the breakdown of the modules used in the TransitSim analysis. TransitSim is compiled into modules of functions and tools to conduct specific analyses. Modules are grouped into five main sections, three (Section 1-3) core sections, an interagency modeling section (Section 4) and a section for extensions (Section 5). Section 4 contains the modules used for interagency modeling but in this study only one agency (MARTA) was used as data source so the functions from section 4 were not included in the python script.

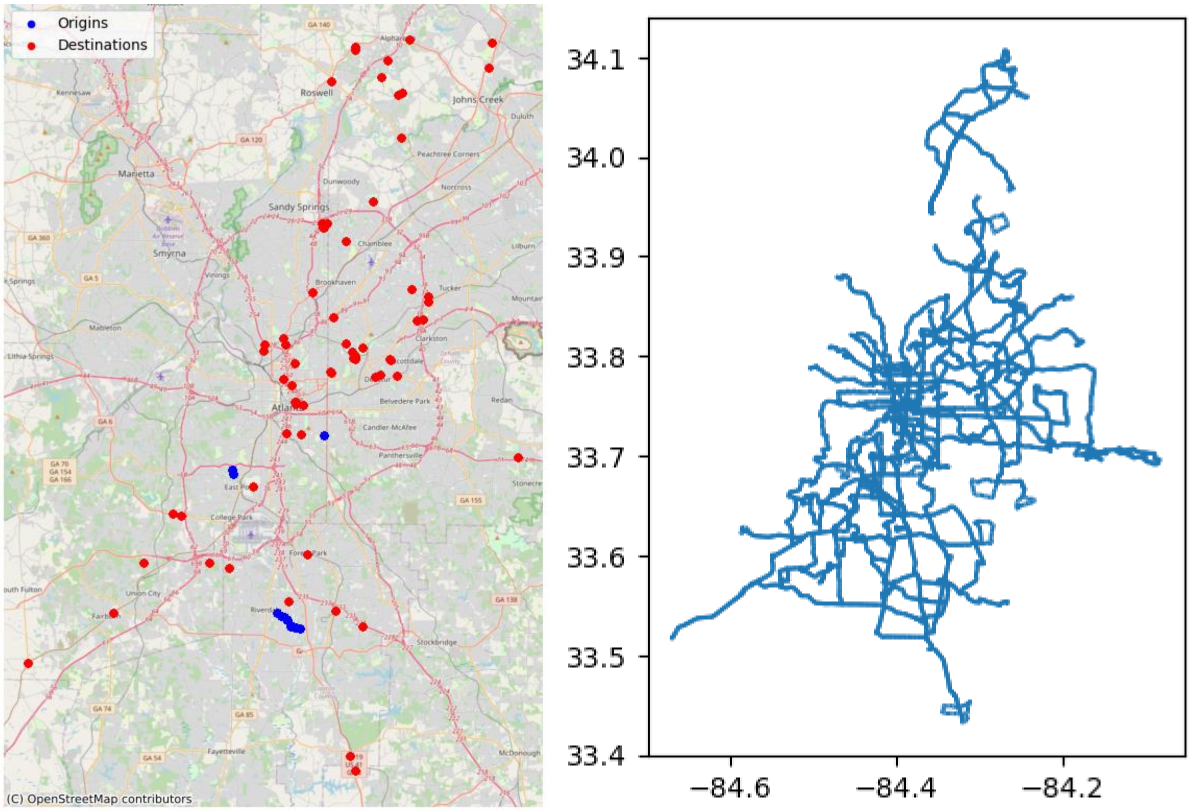

Figure 3.4: Map of the origins and destinations generated by TransitSim (left) & Route map generated by TransitSim (right)

- **TransitSim Inputs:** .csv files are used as the input for the TransitSim. Two types of .csv files are needed for the process to initiate: one with the location data of the origin for the trips and another .csv file with the locational data for the destination of the trips.
    - **Origins:** The origin for TransitSim is the MARTA bus stops. For the test run 25 MARTA bus stops with the highest number of ridership (ridership data from 2021) were used.
    - **Destinations:** The trip destinations for the TransitSim codes were the emergency care and hospitals in the Atlanta Metropolitan Area. The complete destination dataset was used for the calculation to get an idea of how long it takes for one simulation run.

- **TransitSim Outputs:** The transitSim generates two types of outputs: .csv files and shapefiles. There are three output shapefiles:
    - **Trip log:** The trip log file shows the status of the attempted trip, whether the trip was successful or unsuccessful. The successful trip is a trip that could not be completed due to more than five transfers or there were no nearby MARTA bus stops to the destination or make the transfers commuters needed to walk more than .25 miles.

- **Path:** The path file shows the detail of each trip: how many transfers needed for one complete trip, how many sub-trips to complete the trip, the modes, the travel time for each sub-strip, the origin and destination for each of the sub trip, the modes for each of the sub-trips
- **Sum:** The sum file shows the start and end time for the trip and the total travel time for each trip.

3.2.2.1 Network Centered Analysis: For the final calculation the trip origins were selected based on the location and the ridership number of the bus stations:

- **Selection of the Disadvantaged Census Tracts:** The Justice40 data was used to identify the disadvantaged census tract in the Atlanta Metropolitan area. The dataset has three types – disadvantaged, partially disadvantaged, and not disadvantaged. In the three counties that have MARTA bus services there were no partially disadvantaged census tracts. There are only advantages and disadvantages to census tracts. The file containing the Justice40 dataset was downloaded from the ESRI website and ArcGIS Pro was used to select the disadvantaged census tracts in Fulton, Clayton, and DeKalb counties.

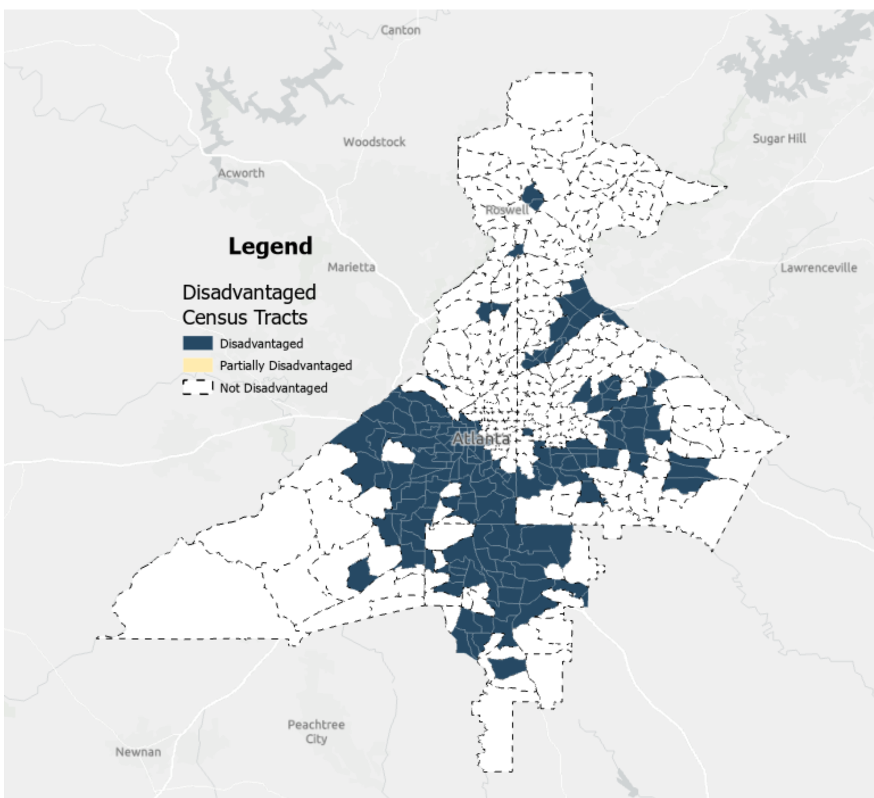

Figure 3.5: Location of the disadvantaged census tracts in the Atlanta Metropolitan Area

- **Selection of the MARTA bus stops that are within the Disadvantaged Census Tracts:** The MARTA bus located within the disadvantaged census tract were selected by using Spatial Join option in the ArcGIS Pro software. A spatial join matches rows from the Join Features values to the Target Features values based on their relative spatial locations. By default, all attributes of the join features are appended to attributes of the target features and copied to the output feature class.

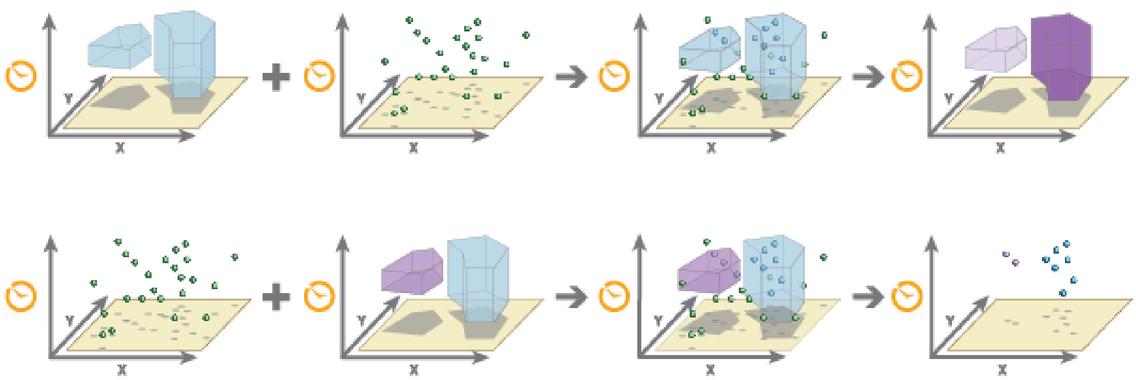

Figure 3.6: Spatial Join examples (Source: ESRI Official Website)

- **Selection of the MARTA bus stops with highest ridership:** Due to time constraints it was not possible to run trip generation simulation for all the MARTA bus stops that are within the boundaries of the Disadvantaged census tracts. There are almost three thousand MARTA bus stops located in the disadvantaged census tracts. The top 500 MARTA Stations ranked based on their average daily ridership number from 2021 were selected for the calculation.
- **Selection of the MARTA Bus stop with highest ridership and lowest ridership:** 100 MARTA bus stops with the highest number and another 100 MARTA bus stops with the lowest number of ridership were also selected to make a comparison.

Running TransitSim with the Final Dataset: The final script was run with 50 MARTA bus stops each time. The start time for the bus trips was 9:00 on a Monday. Different Bus routes have different schedules but to make the calculation simpler the boarding time was kept the same. Since the MARTA bus schedule remained the same throughout the weekdays the script was only run for Monday.

Due to various reasons found in the background study (insurance, specialist, regular checkup etc.) the patients cannot always go to the nearest healthcare facility available to them, so it is important to have somewhat accessibility to all the healthcare facilities. That is why all the healthcare locations were used as destinations for all the bus stops.

The number of transfers was limited to 5 transfers and the walk threshold was defined as half a mile. After completing the simulation runs in the Python 3.10 environment all the results were compiled and MARTA stations that have the highest average trip time and healthcare facilities that have the highest average trip time from the MARTA bus stops were identified. During the simulation run some errors and warning signs were generated by the Python Environment such as discrepancy in time, distance for a few trips and abnormal geometrics for a few trips.

Step 1: Compiling all the Trip Durations from the TransitSim Outputs			
Origin	**Destination**	**Trip id**	**Travel Time (hr)**
A	X	trip_001	1
A	Y	trip_002	2
A	Z	trip_003	3
B	X	trip_004	2
B	Y	trip_005	0.5
B	Z	trip_006	1
C	X	trip_007	3
C	Y	trip_008	1

Step 2:			
Origin	**Calculation**	**Total Travel Time (hr)**	**Average Travel Time (hr)**
A	Travel time for trip_001 + Travel time for trip_002 + Travel time for trip_003	6	2
B	Travel time for trip_004 + Travel time for trip_005 + Travel time for trip_006	3.5	1.67
C	Travel time for trip_007 + Travel time for trip_008	4	2

Step 3: Ranking	
Origin	**Ranking Based on Average Time Taken to reach the Healthcare Facilities**
MARTA Bus Stop A	2
MARTA Bus Stop B	1
MARTA Bus Stop C	2

Chart 3.1: Calculation steps to find the average travel time for the selected MARTA bus stops

Step 1: Compiling all the Trip Durations from the TransitSim Outputs			
Origin	**Destination**	**Trip id**	**Travel Time (hr)**
A	X	trip_001	1
A	Y	trip_002	2
A	Z	trip_003	3
B	X	trip_004	2
B	Y	trip_005	0.5
B	Z	trip_006	1
C	X	trip_007	3
C	Y	trip_008	1

Step 2:			
Destination	**Calculation**	**Total Travel Time (hr)**	**Average Travel Time (hr)**
X	Travel time for trip_001 + Travel time for trip_004 + Travel time for trip_007	7	2.3
Y	Travel time for trip_002 + Travel time for trip_005 + Travel time for trip_008	3.5	1.67
Z	Travel time for trip_006 + Travel time for trip_003	4	2

Step 3: Ranking	
Destination	**Ranking Based on Average Time Taken to reach the Healthcare Facilities**
X	3
Y	1
Z	2

Chart 3.2: Calculation Steps to Find the Average Travel Time to Reach Each Healthcare Facilities

3.2.2.2 Hospital Centered Analysis: For the analysis in this section, first the service area for a few selected destinations were identified. Next, the bus stops that are located within the service area were selected. Among those bus stops the ones that are located the farthest from the destinations were identified for each of the routes. This was done to minimize the calculation time and in theory, by calculating the time taken to reach the destination from the bus stops located the farthest away from the destination, the longest travel time can be found for each route.

Analyzing Results: The TransitSim results provided the total time needed to complete each trip, the time needed to transfer from one bus to another and how many sub-trips each trip had. The results were exported as .csv files. After completing all the simulation cycle all the results were compiled together and each trip was assigned as a unique trip number. The trips were arranged based on the origin (the MARTA bus stop) and the total amount of time needed from a MARTA Station to get to all the destinations was summed up. The total time needed to get to all the destinations from the origin was arranged to find out the stations that had the greatest travel time. From every origin half a mile buffer was created to find the serving area of that MARTA stop. All the census tracts within the buffer areas were selected to generate a map that shows the average travel time to the healthcare facilities from the origin MARTA bus stops.

Generating Recommendations and Identifying the Limitations of the Study: Based on the findings of the analysis, some recommendations were generated for the improvement of the MARTA bus stops. The study has some limitations, and these limitations were also noted down in the write up. Addressing the limitations would help to produce better results and can be used to improve the route network of the MARTA Bus system.

CHAPTER 4: CASE STUDY RESULTS

4.1 Transit Dependent Population:

The collected ACS data was tested to see if the variables are normally distributed. Based on the test result, it was decided that the variables are not normally distributed. So, the Mann–Whitney U test was performed on the variable for the mean test.

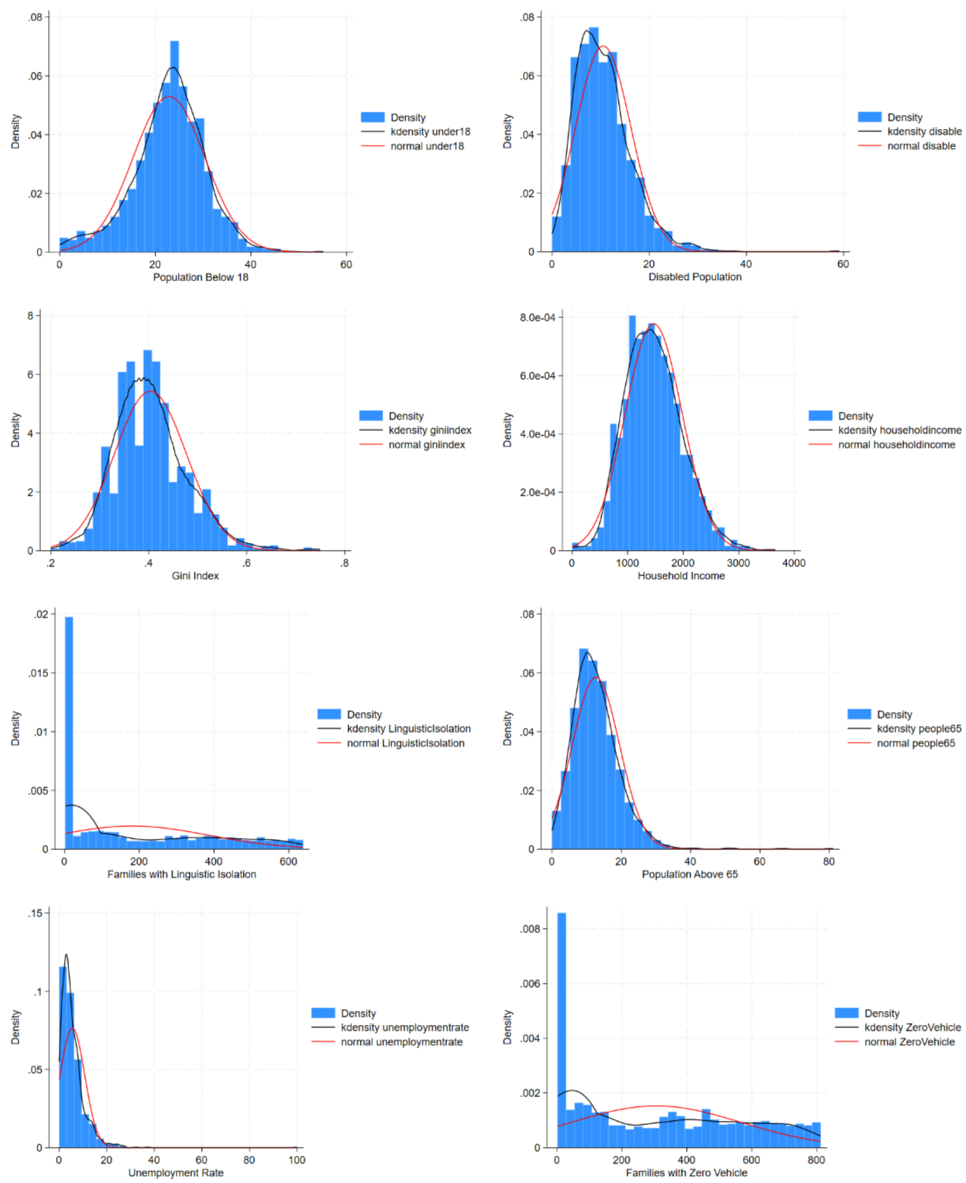

Figure 4.1.1: Distribution of the collected data

Figure 4.1.1 shows the distribution of the different variables that are used to define whether a population is transit dependent. The test results found that in some cases the census tracts with MARTA bus stops are more vulnerable compared to the census tracts without MARTA bus stops. And in some cases, it's the other way around. For example, in terms of families with zero vehicles, the census tracts with MARTA bus service are more vulnerable. Meaning, these census tracts have a higher percentage of families without vehicles, so these families are more transit dependent and vulnerable in terms of their transportation choices and accessibility. Again, when looked at the percentage of population younger than 18 years, it was found that the census tracts without MARTA service are more vulnerable. The census tracts without MARTA service have a higher percentage of population below 18 which means more percentage of people in those areas do not have a driver's license compared to the areas with MARTA service.

To understand the ADA accessibility of the MARTA stations, the wheelchair accessibility data was also collected from the MARTA website. Most of the MARTA bus stops had missing values so it was not possible to understand if those stops were wheelchair accessible. 62 % of the stops were found to have wheelchair accessibility.

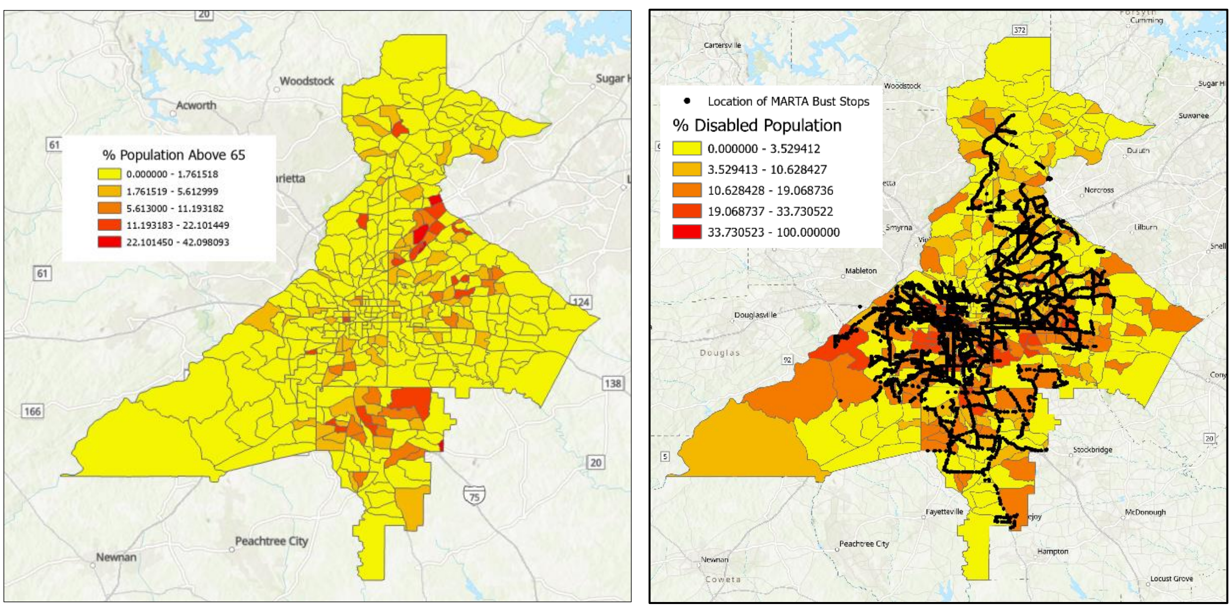

Figure 4.1.4: Distribution of transit dependent population in the study area: Population above 65 (left) & Disabled Population (right)

4.2 Disadvantaged Census Tracts:

Using the Justice40 data, the census tracts that are disadvantaged in the census tracts were identified. Using the Spatial join feature in the ArcGIS Pro software the MARTA station inside the disadvantaged census tracts or close to those tracts were identified. For the travel time analysis, the first 300 census tracts were identified based on the ridership number. The bus stops with the highest ridership are more likely to be used by the most people in the area. So, understanding the accessibility of those bus stations would be helpful to get an idea of the overall accessibility of the area surrounding the bus stops.

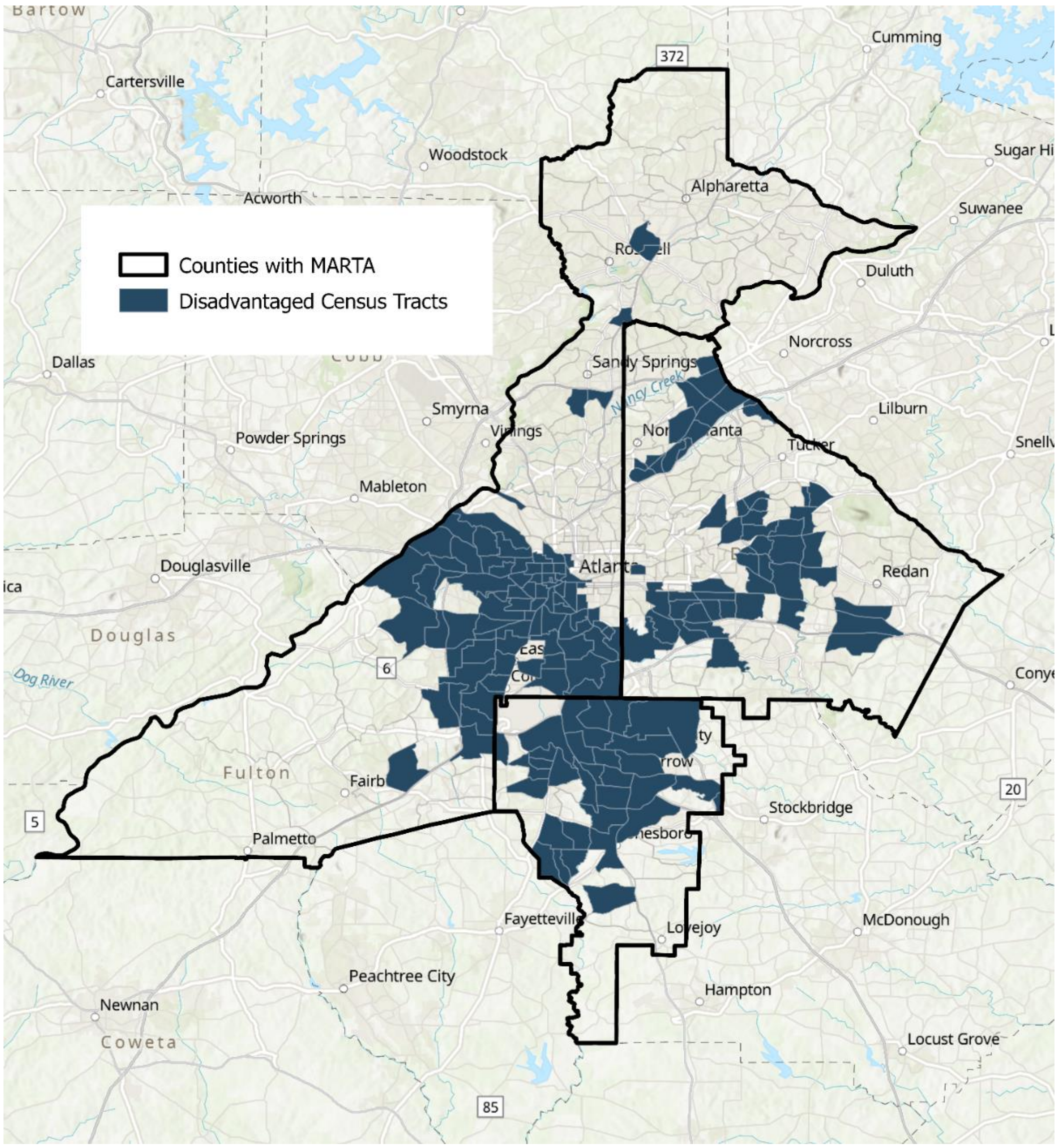

Figure 4.2.1: Location of the disadvantaged census tracts based on the Justice40 data

4.3 Network Centered Travel Time Analysis:

For comparison, 100 MARTA bus stops with the most and least ridership were also selected for travel time analysis. Table 3.3.1 shows the total number of trips that were attempted by the TransitSim Model and the success rate of those trips. The MARTA stops with the lowest ridership has the highest number of unsuccessful trips.

Table 4.3.1: Trip Success Rate

Category	Trips from Top 100 Bus Stations	Trips from the Bottom 100 Bus Stations	Trips from Top 300 Bus Stations inside the Disadvantages Census Tracts
Total Trip attempt	7001	7146	21012
Success	5932	5121	16380
% Unsuccessful	15 %	28%	22 %

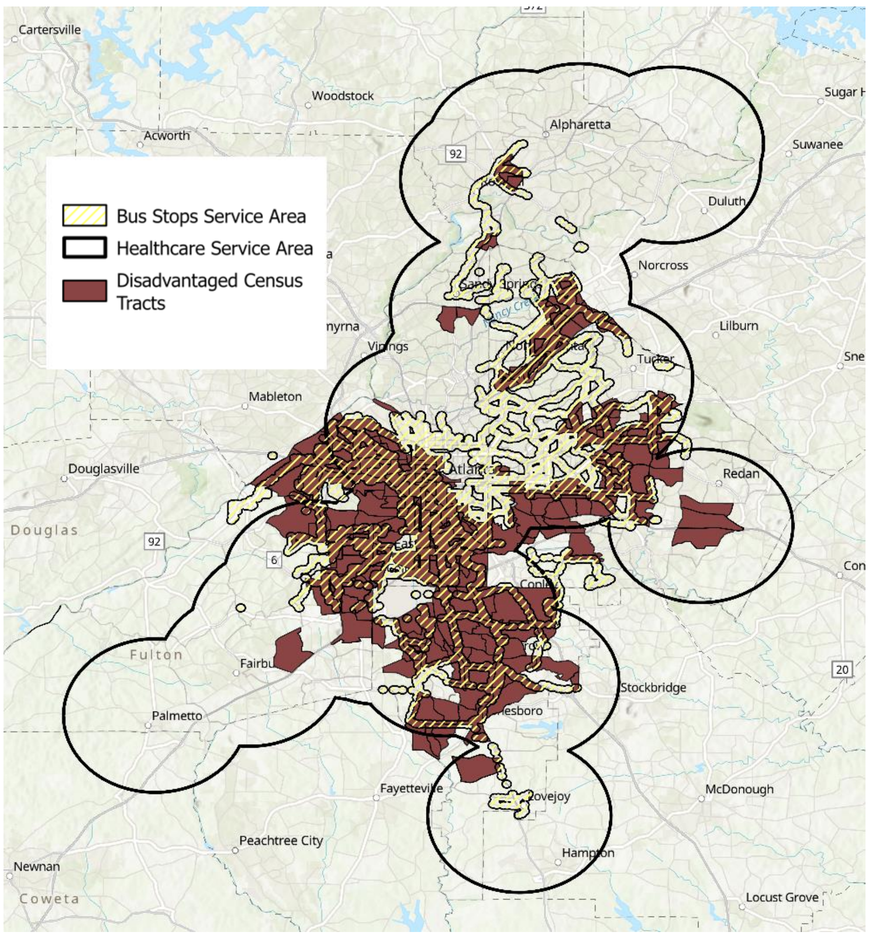

Figure 4.3.1: Service area of the healthcare facilities

Figure 4.3.1 shows the service area of the healthcare facilities. Most of the areas that are serviced by MARTA bus routes fall within the catchment area of the healthcare facilities. So, in this section, the study will investigate how accessible area these healthcare facilities are in terms of spatial accessibility via public transit. Unfortunately, most of the healthcare facilities are located outside of the disadvantage area so the spatial distribution of the healthcare service is not great in the rea but with proper public transit the situation can be improved, and gaps can be minimized.

4.3.1 Bus Stops with High Ridership

The MARTA bus stops were sorted based on the 2021 average daily ridership for the year 2021. The top 100 MARTA bus stops with the most ridership were selected for the analysis. Figure 4.3.1.1 shows the location of the selected bus stops and the location of the healthcare facilities. The dark blue cells in figure 4.3.1.1 show the locations of the disadvantaged census tracts. Most of the hospitals and clinics selected as the destinations for the analysis are in the non-disadvantaged census tracts. And almost 60% of the selected bus stops are within the disadvantaged areas. These could be either due to less access to any other modes of transportation or, better service provided by the MARTA bus service or both.

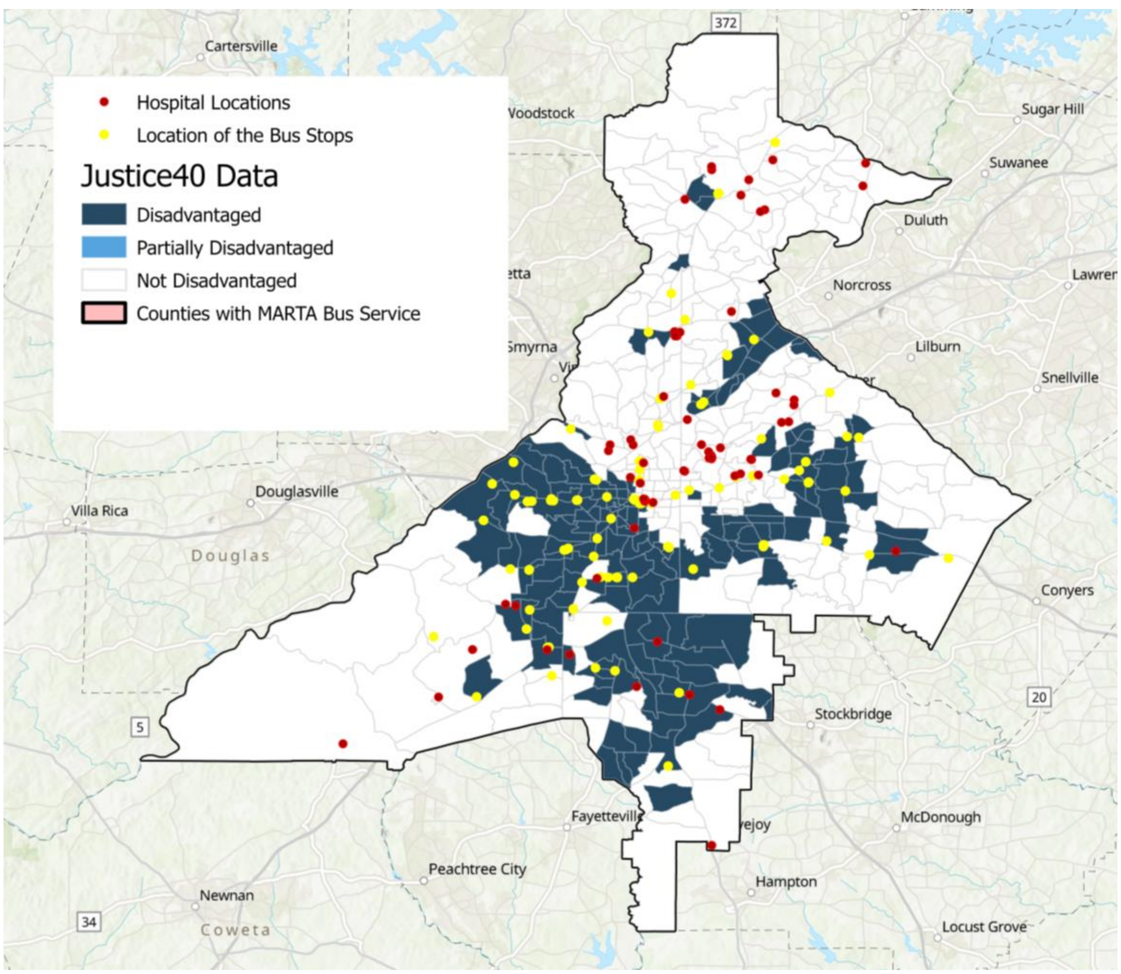

Figure 4.3.1.1: Location of the origins and the destinations

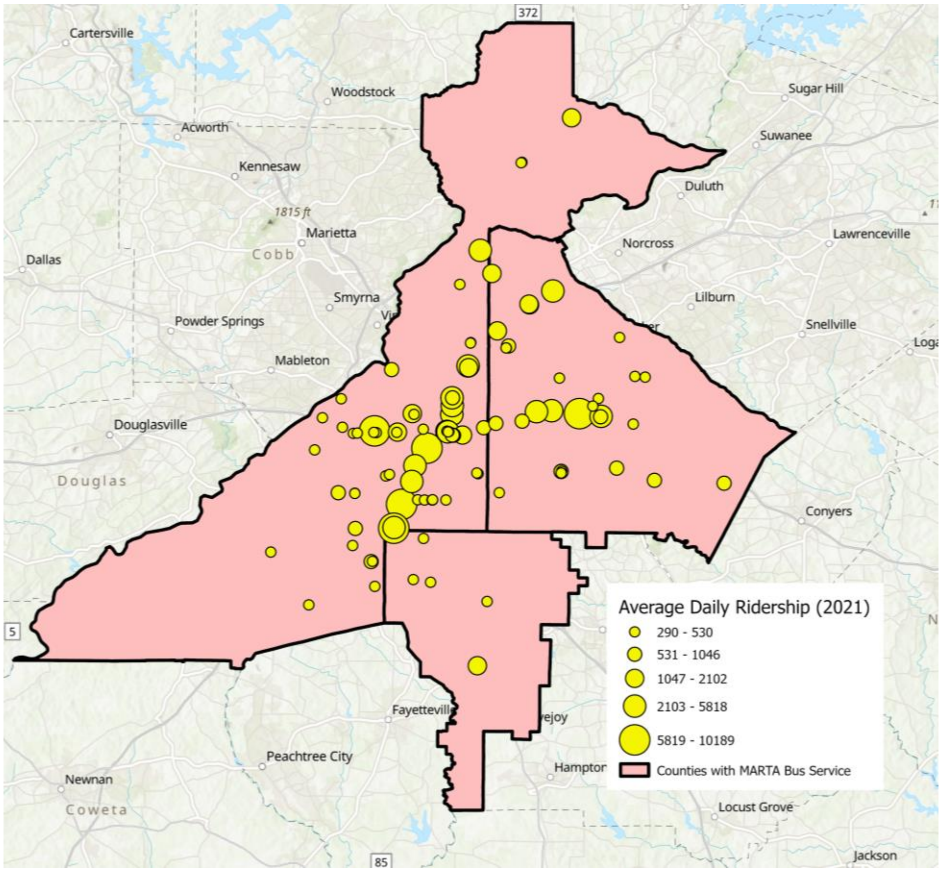

Figure 4.3.1.2: Ridership number for the top 100 MARTA bus stop

Figure 4.3.1.2 shows the range of ridership for the selected MARTA bus stops. The bigger the circle the more the ridership number. Some of the bus stops have ridership as high as 10,000 so it can be said improving the overall network will help a lot of people to reach the healthcare services and make the healthcare services more spatially accessible.

Figure 4.3.1.3 shows the average time taken to reach the healthcare facilities from all the bus stops. The bigger the circle the more time it takes to reach the healthcare facility from all the selected bus stops on average. Which means the smaller the circle the more accessible the facilities area. All the healthcare facilities are accessible from almost 80 % of the bus stops. Piedmont Urgent Care clinic is the most accessible one & Emergency Room at Northside Hospital is the least accessible one. Average Travel Time is 243 minutes for the healthcare facilities.

Figure 4.3.1.4 shows the average time for each of the bus stops which means how long it takes on an average to reach all the facilities from one bus stop. The bigger the circle around the bus stops the less accessible it is.

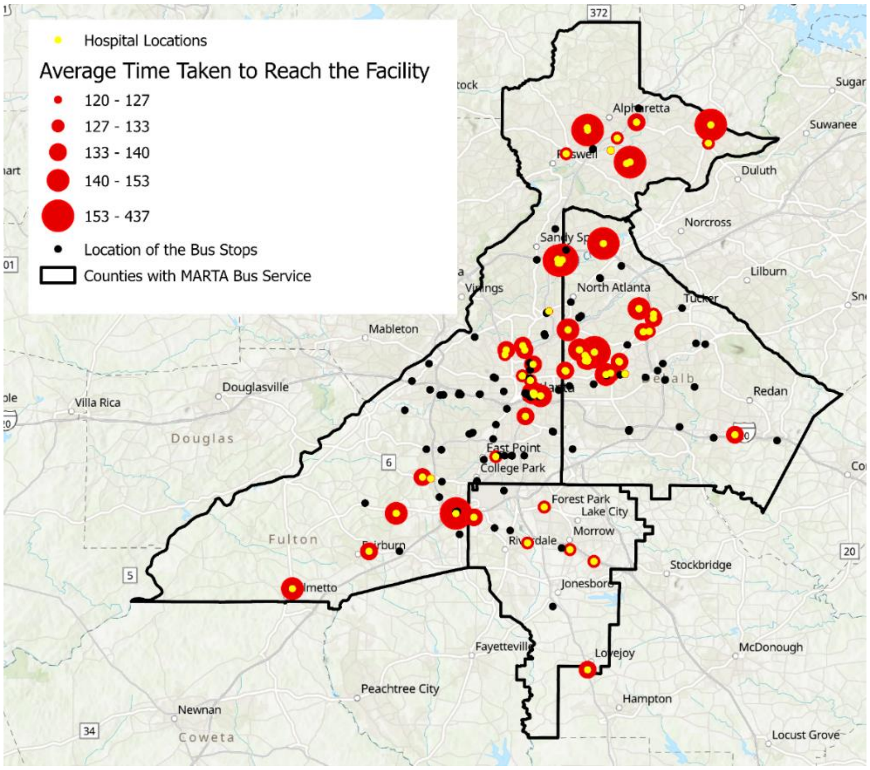

Figure 4.3.1.3: Average time taken to reach the facilities from the selected MARTA bus stops with high ridership

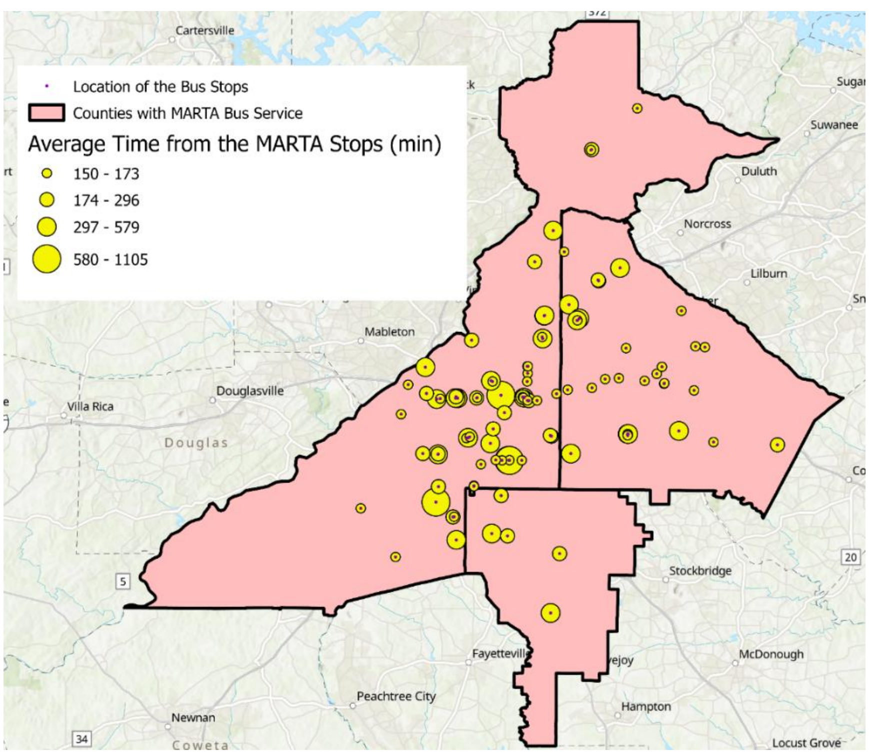

Figure 4.3.1.4: Average time taken to reach all the facilities from every bus stop

In both of these figures, Since the circles show an average time and travel time for all the destinations it is shows the overall network accessibility for these destinations. In Figure 4.3.1.4 the bus stops with similar travel time are mostly located on the same route which can mean that some of the routes and very well-connected and have higher accessibility and thus the stops on those routes have lower travel time. And those MARTA stops with higher travel time are located on less efficient routes and take longer to reach destinations.

4.3.2 Bus Stops with Low Ridership

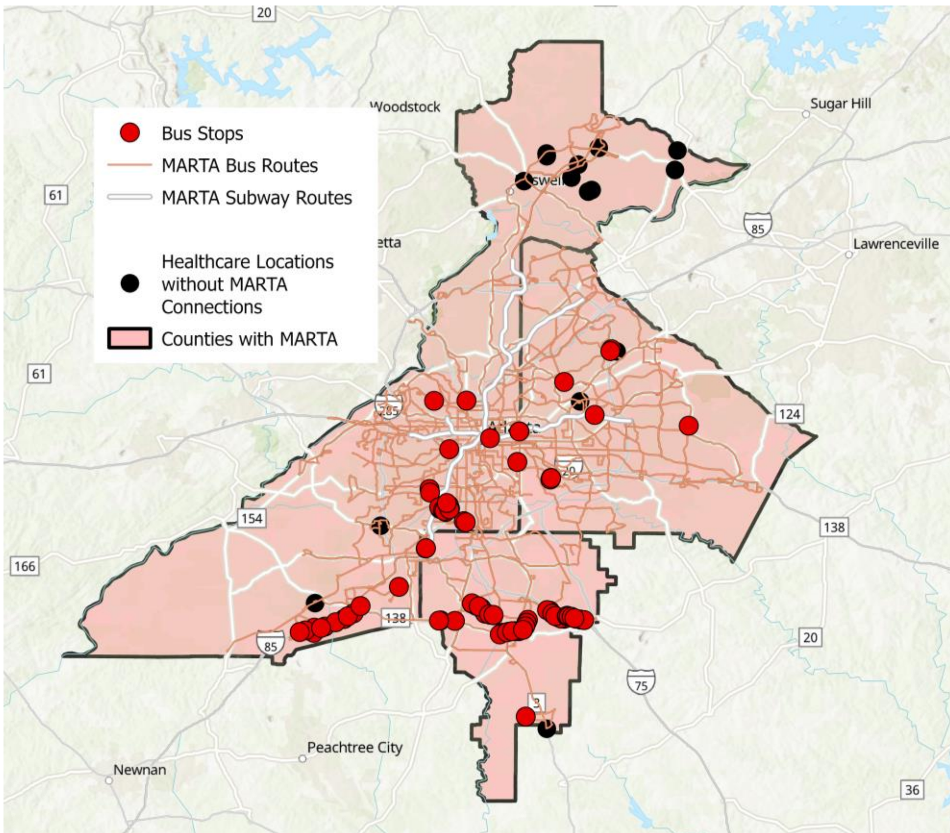

Figure 4.3.2.1: Healthcare Facilities without MARTA Accessibility

Figure 4.3.2.1 shows the location of the healthcare facilities that are not accessible from any of the bus stops. These healthcare facilities are still on the existing MARTA bus routes or every close to the MARTA bus routes but since TransitSim did not generate any successful trips for this location it means these are very inaccessible locations.

Figure 4.3.2.2 shows the average travel time taken to reach the facilities. In comparison to the bus stops with higher ridership, the bus stops with low ridership have a shorter overall travel time but many of the healthcare facilities are not accessible from these stops so shorter travel time does not mean higher accessibility.

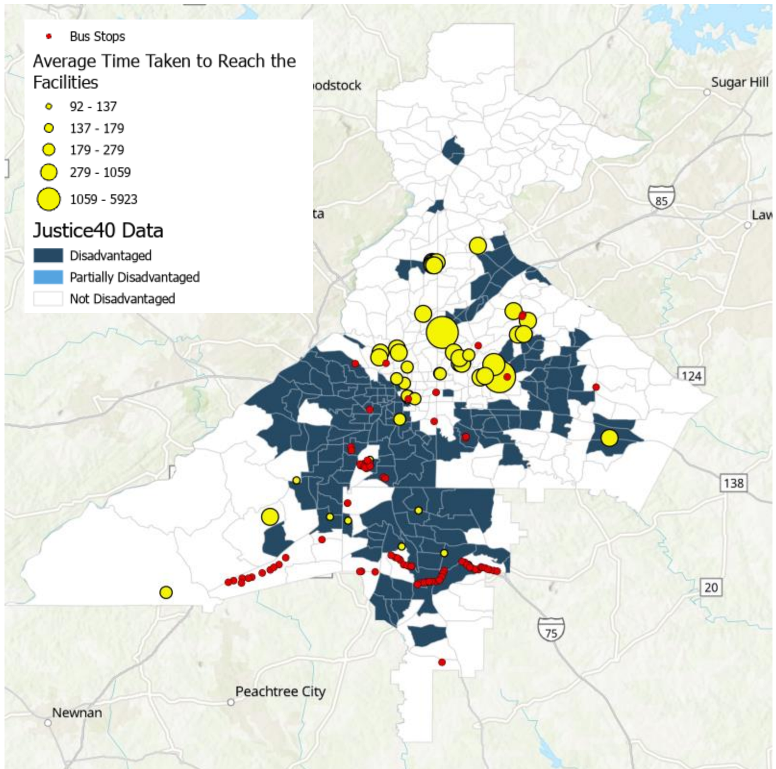

Figure 4.3.2.2: Average Travel Time for Healthcare Facilities

4.3.3 Bus Stops within the Disadvantaged Area

Based on the ridership data, the MARTA bus within the disadvantaged areas sorted and the top 300 bus stops were selected for the analysis. Not all the healthcare facilities were accessible via all the selected bus stops. The inaccessible facilities from these stops are mostly the same ones that are inaccessible from the bus stops with low ridership. Figure 4.3.3.1 shows the location of the healthcare facilities that are inaccessible from the bus stops. Overall these bus stops have shorter travel time compared to the bus stops with higher ridership and bus stops with low riderships. But many of the healthcare facilities are not acceisble from many bus stops so having shorter time does not mean that the bus stop has higer accesibility. Figure 4.3.3.3 shows the location of the bus stops that take more than 3 hours on average to reach the destinations. So, these bus stops offer overall lower network accessibility.

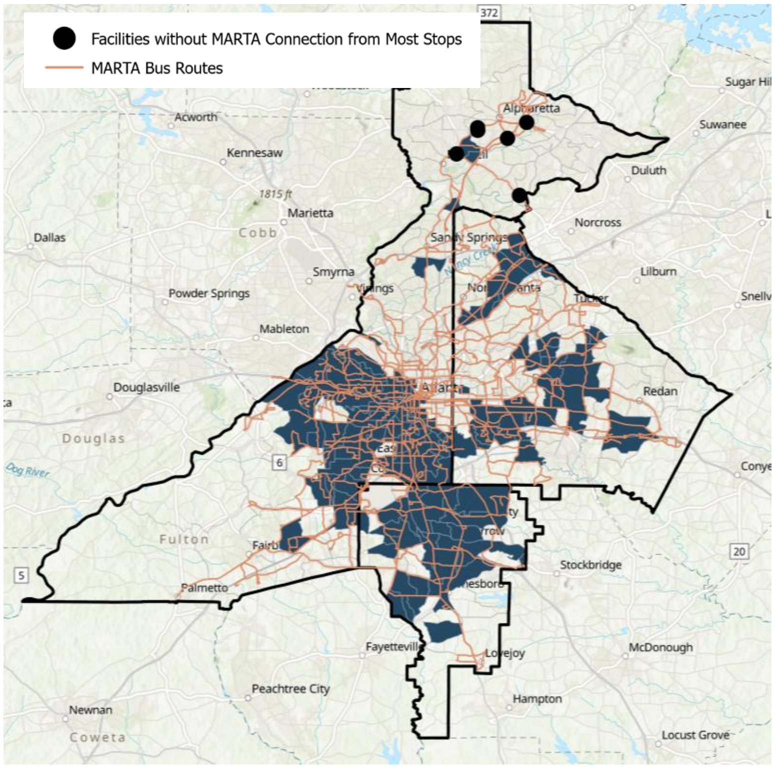

Figure 4.3.3.1: Location of the Healthcare Facilities that are not accessible through MARTA Bus service

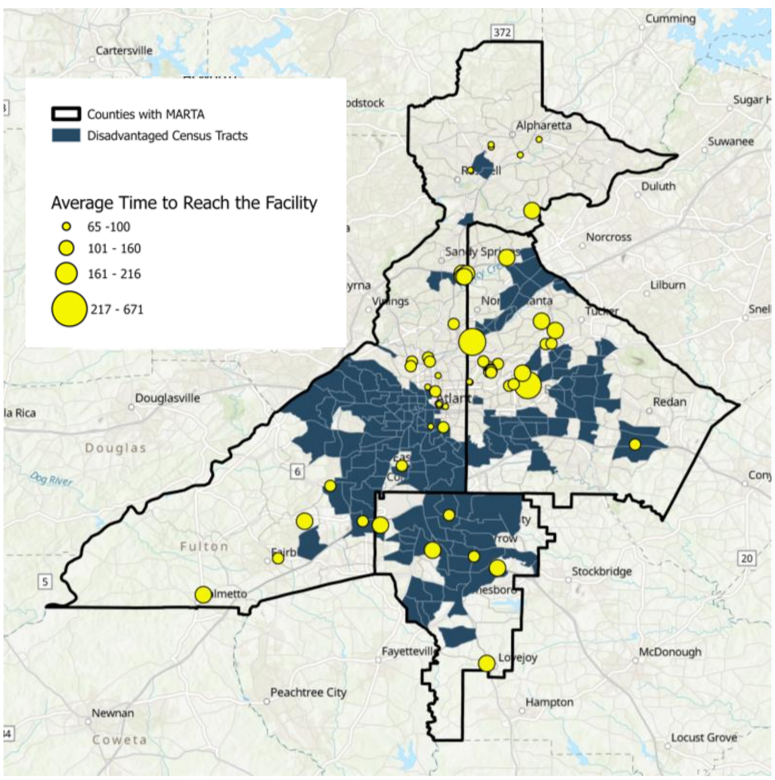

Figure 4.3.3.2: Average travel time for each healthcare facility

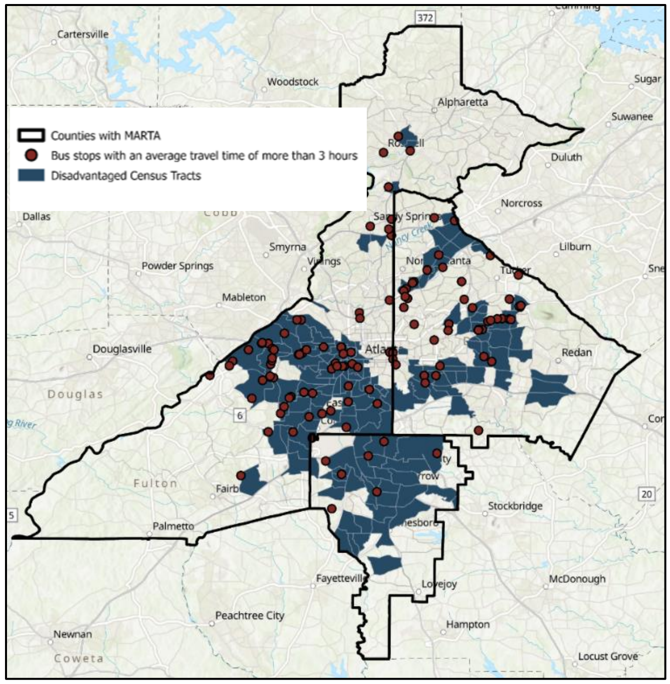

Figure 4.3.3.3: Bus stops with an average travel time higher than 3 hours

4.3.4 Healthcare Centered Analysis:

The previous section analyses the overall accessibility of the MARTA transit network, but it is also important to understand the accessibility to each healthcare facility. Generally, urban health care facilities have a service area of 5 miles (Gresenz et al., 2004). To understand the destination level spatial accessibility eight healthcare was selected. Table 4.3.4.1 shows the details of the selected hospitals. Figure 4.3.4.1 shows the location of the healthcare facilities. These healthcare facilities are located either inside the disadvantaged area or very close to the disadvantaged area. These locations are also accessible from the surrounding area and most MARTA bus stops (bus stops with high ridership. Bus stops with low ridership, bus stops within disadvantaged area) which was found in the analysis from the previous section.

This section also shows the distribution of the travel time for each of the locations. The bus stops were selected based on their location. Each of these bus stops is the stop located on the farthest corner of the route they are located on within the service area of the healthcare facilities. The figures showing the service areas of the selected healthcare facilities also show the areas that are not serviced by the MARTA service, and there are gaps in the existing public transit service.

Table 4.3.4.1: Description of the selected healthcare facilities

Name	Has Emergency Service	Type of Facility
DeKalb Medical	Yes	Hospital
Southern Regional Medical Center	Yes	Hospital
Emory Healthcare	Yes	Hospital
Egleston Hospital	Yes	Hospital
Med Post Urgent Care	Yes	Clinic
WellStar Atlanta Medical Center South	Yes	Hospital
Atlanta Allergy & Asthma	Yes	Clinic
Peach ford Hospital	No	Hospital

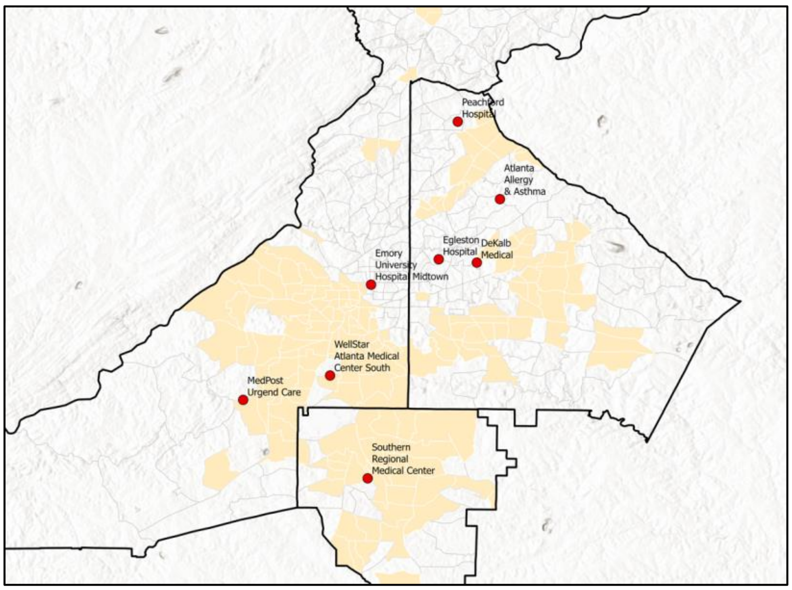

Figure 4.3.4.1: Location of the selected healthcare facilities

Table 4.3.4.2: Travel time (minute) details for the healthcare facilities

Name	Average time	Shortest time	Longest time	Median time
DeKalb Medical	13567	21	55855	63
Southern Regional Medical Center	32	17	55	29
Emory Healthcare	2905	8	49660	44
Egleston Hospital	3923	7	24891	56
Med Post Urgent Care	45	7	417	31
WellStar Atlanta Medical Center South	48456	22	189403	10848
Atlanta Allergy & Asthma	53	12	568	33
Peach ford Hospital	46	10	127	51

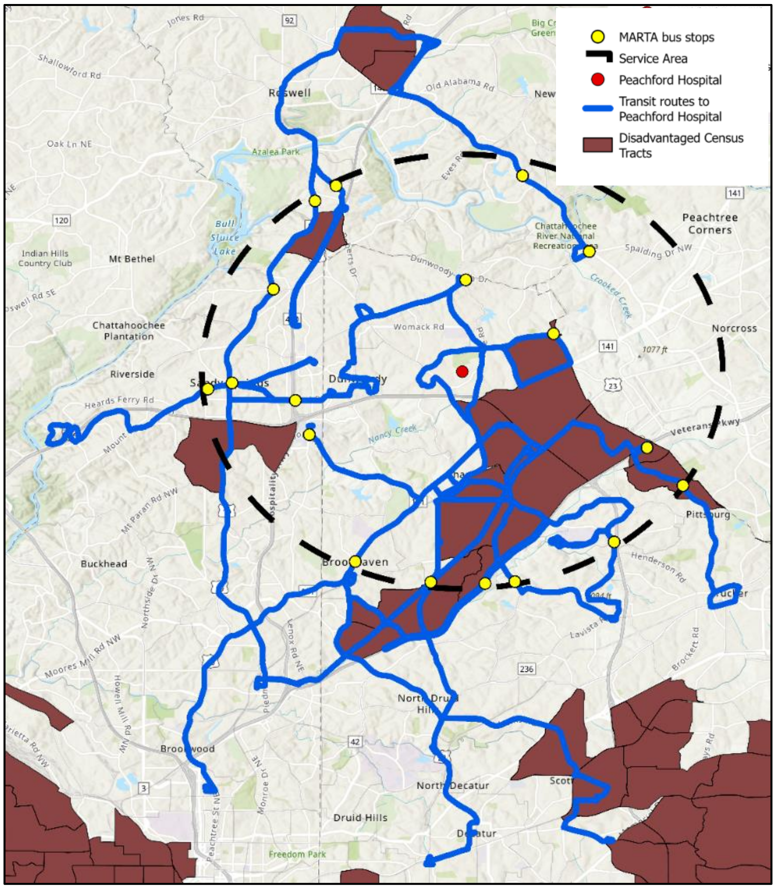

Figure 4.3.4.2: Location of the bus transit routes to reach the Peach Ford hospital

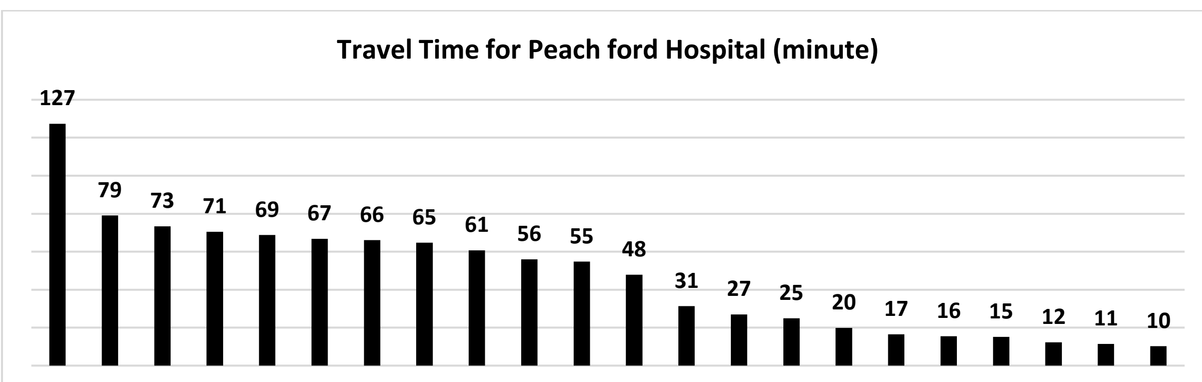

Chart 4.3.4.1: Distribution of the travel time for Peach ford hospital

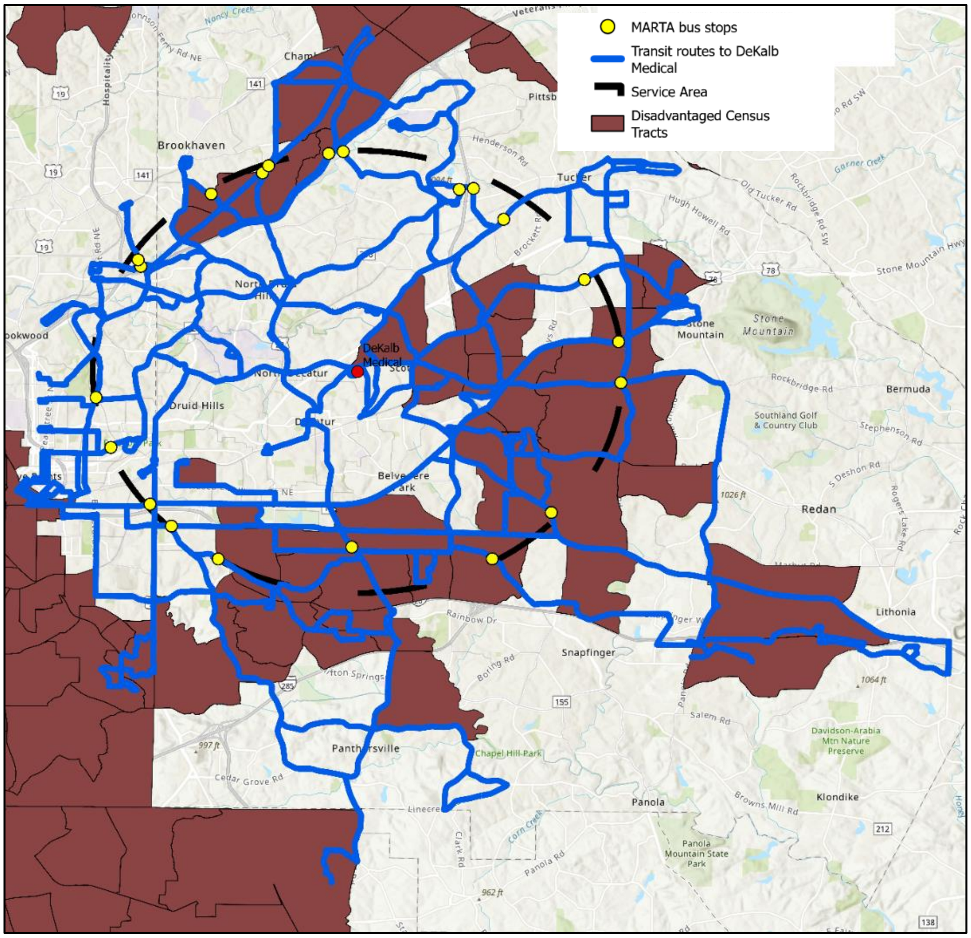

Figure 4.3.4.3: Location of the bus transit routes to reach the DeKalb Medical

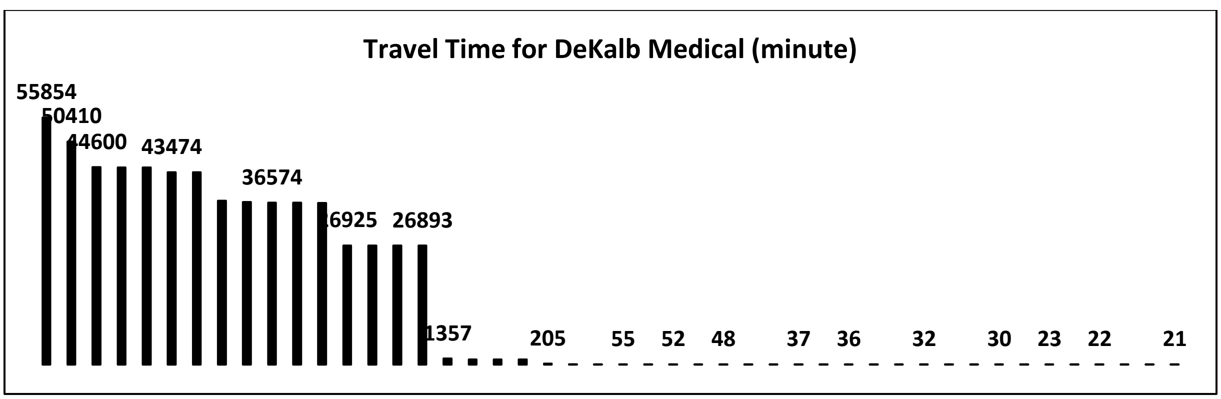

Chart 4.3.4.2: Distribution of the travel time for DeKalb medical

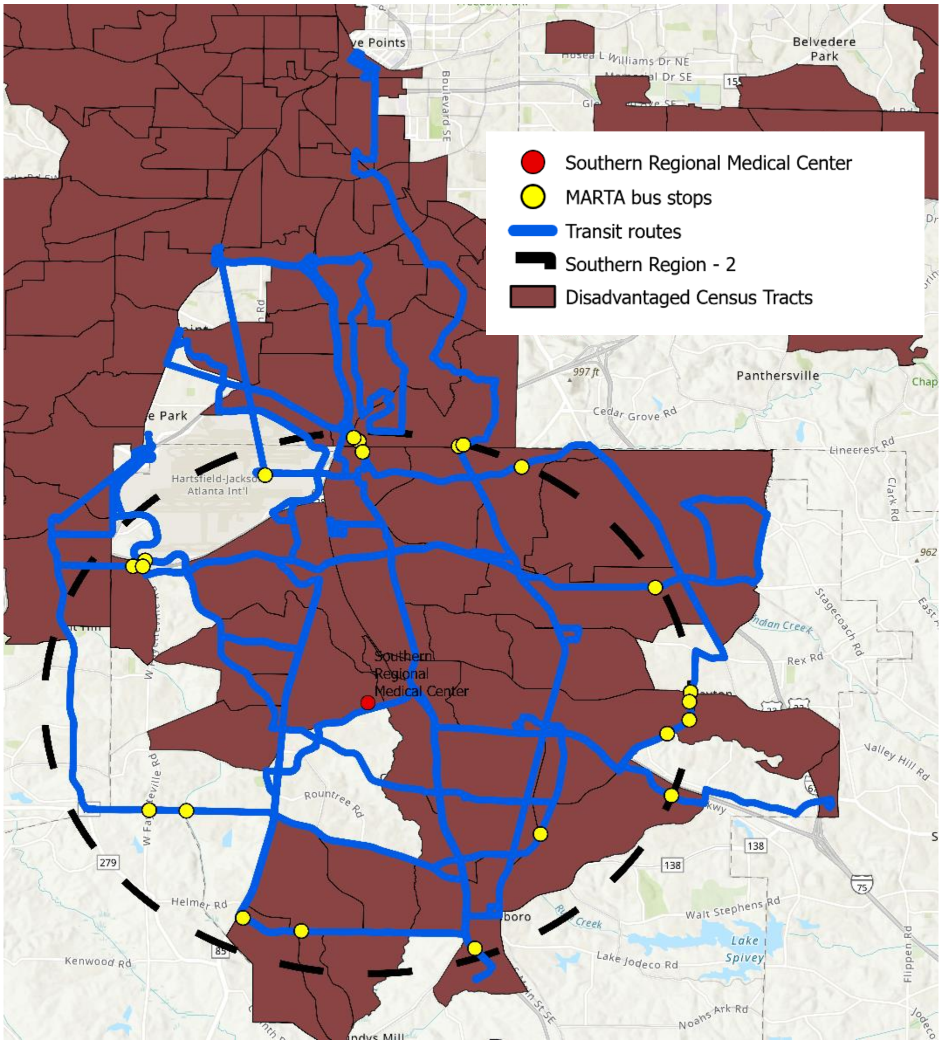

Figure 4.3.4.4: Location of the bus transit routes to reach the Southern Regional Medical Center

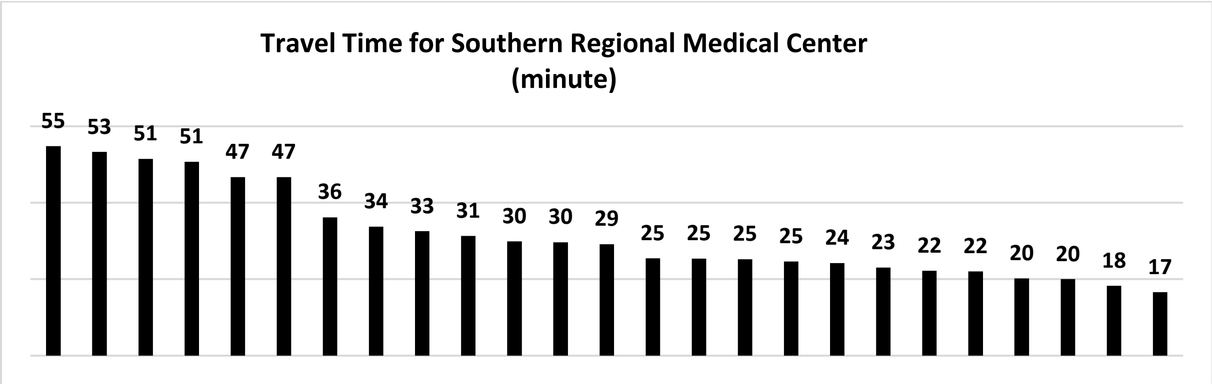

Chart 4.3.4.3: Distribution of the travel time for Southern regional medical center

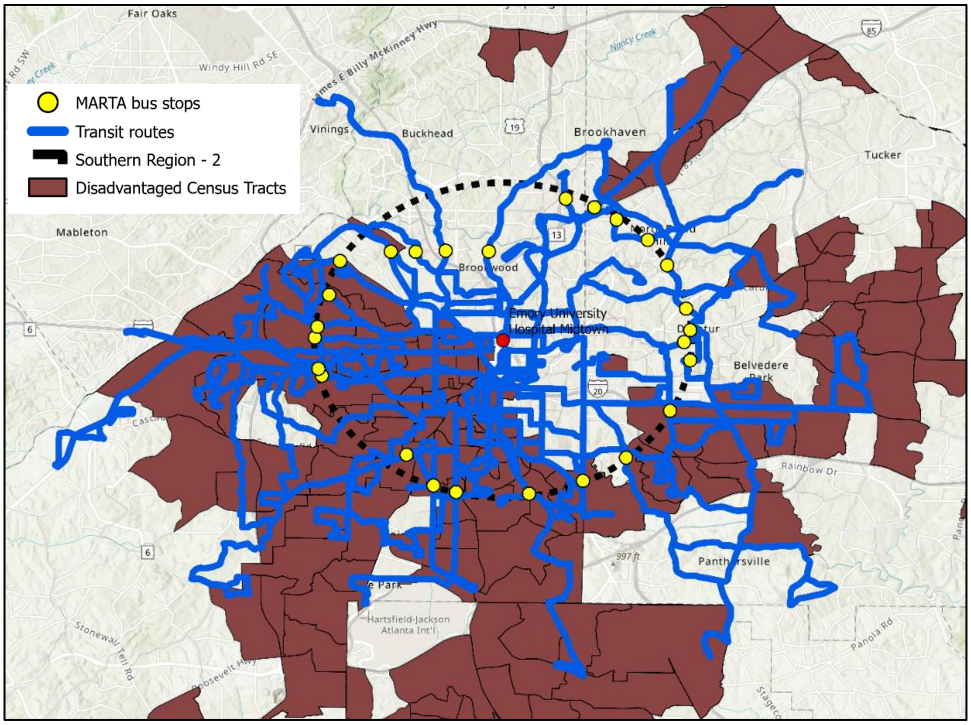

Figure 4.3.4.5: Location of the bus transit routes to reach the Emory hospital

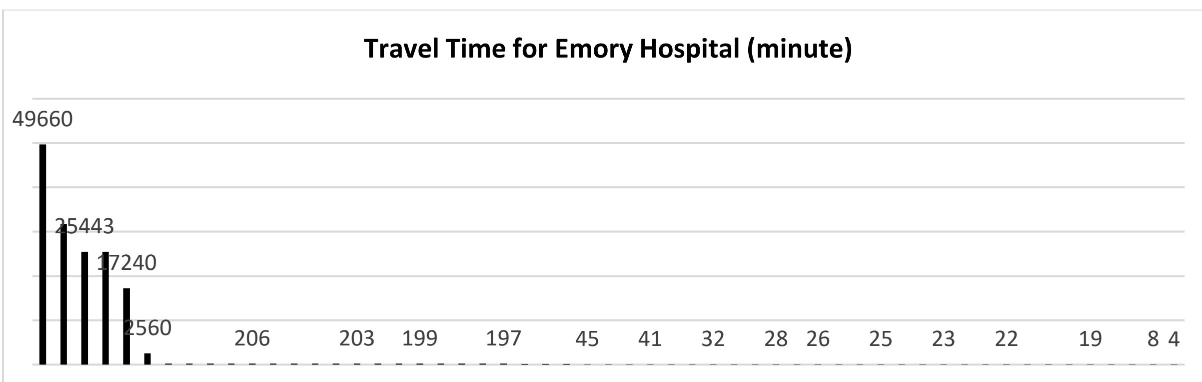

Chart 4.3.4.4: Distribution of the travel time for Emory hospital

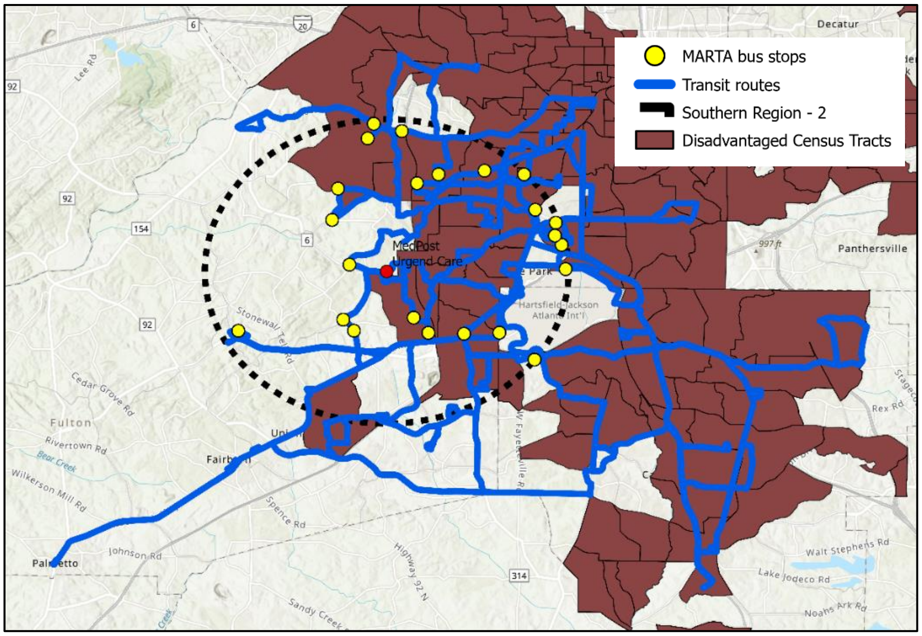

Figure 4.3.4.6: Location of the bus transit routes to reach the Med post urgent care

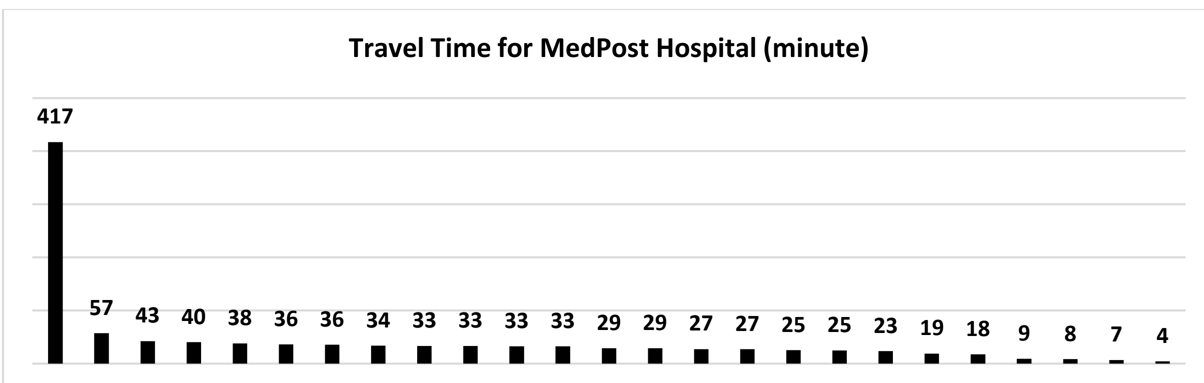

Chart 4.3.4.5: Distribution of the travel time for Med post hospital

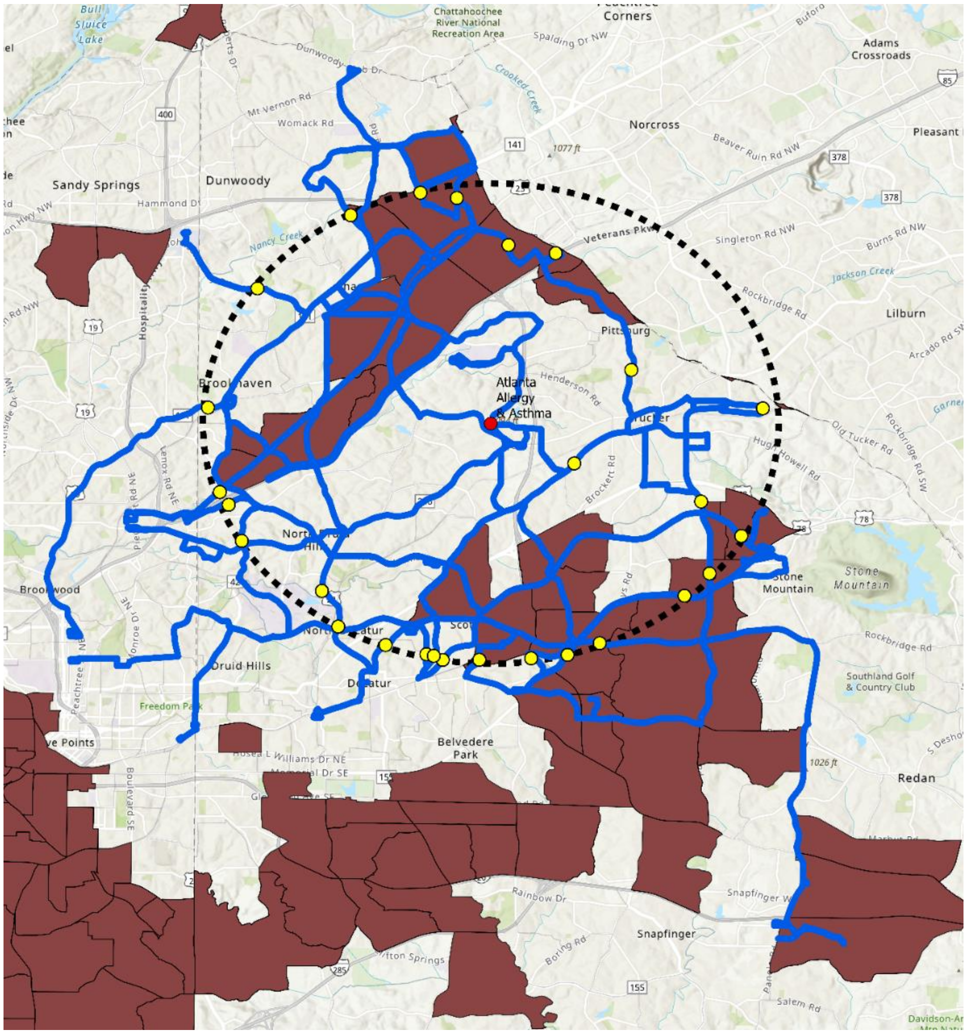

Figure 4.3.4.7: Location of the bus transit routes to reach the Allergy & asthma hospital

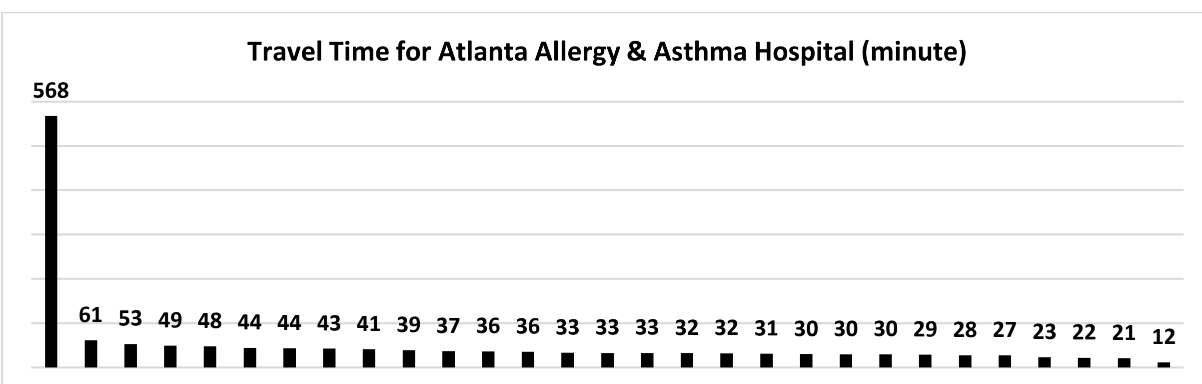

Chart 4.3.4.6: Distribution of the travel time for Allergy & asthma hospital

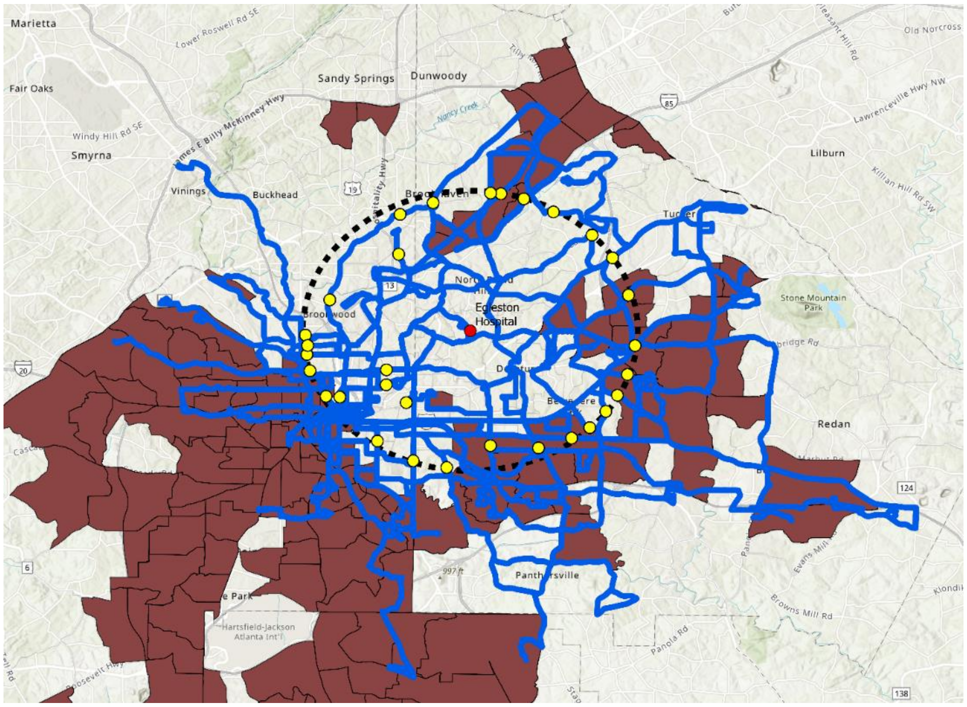

Figure 4.3.4.8: Location of the bus transit routes to reach the Egleston hospital

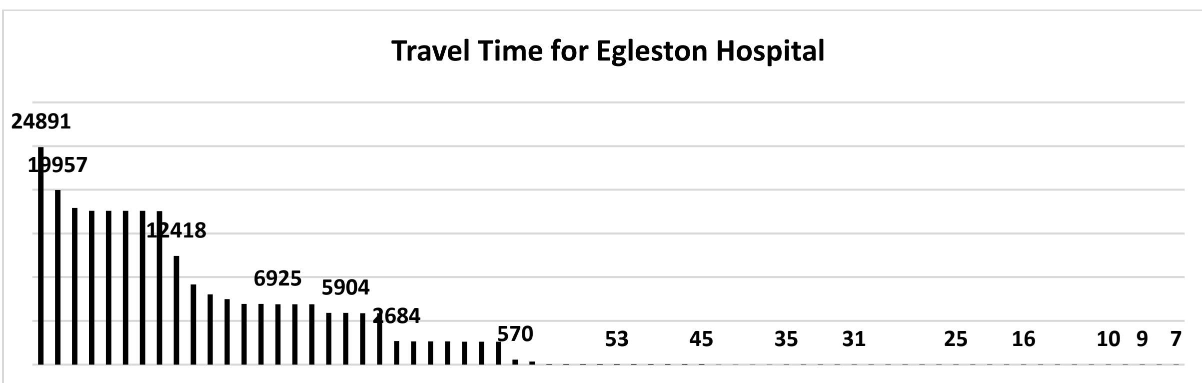

Chart 4.3.4.7: Distribution of the travel time for Egleston hospital

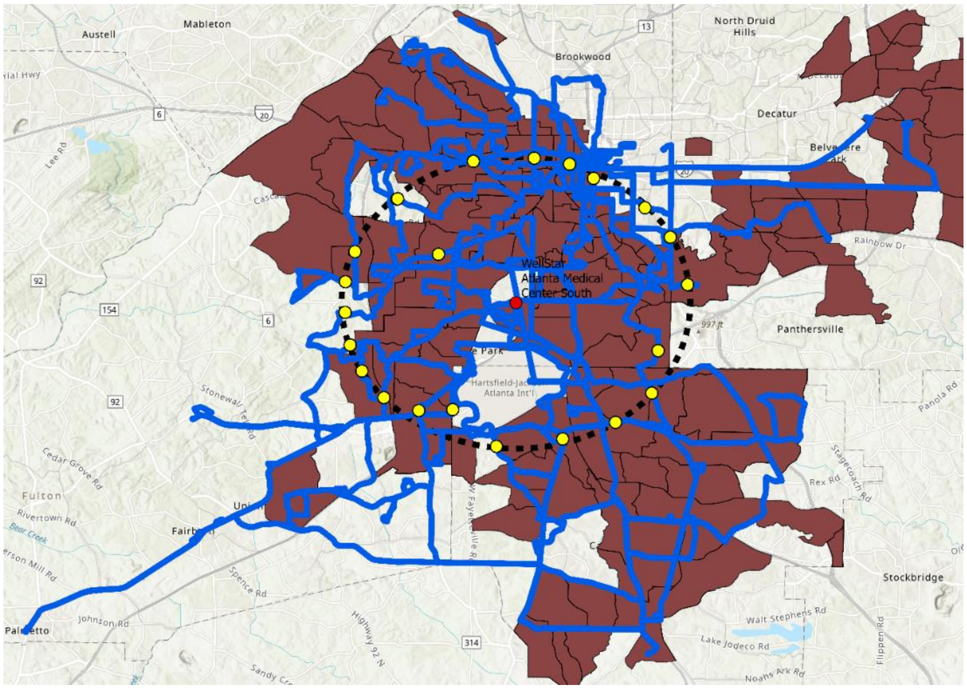

Figure 4.3.4.9: Location of the bus transit routes to reach the Wellstar hospital

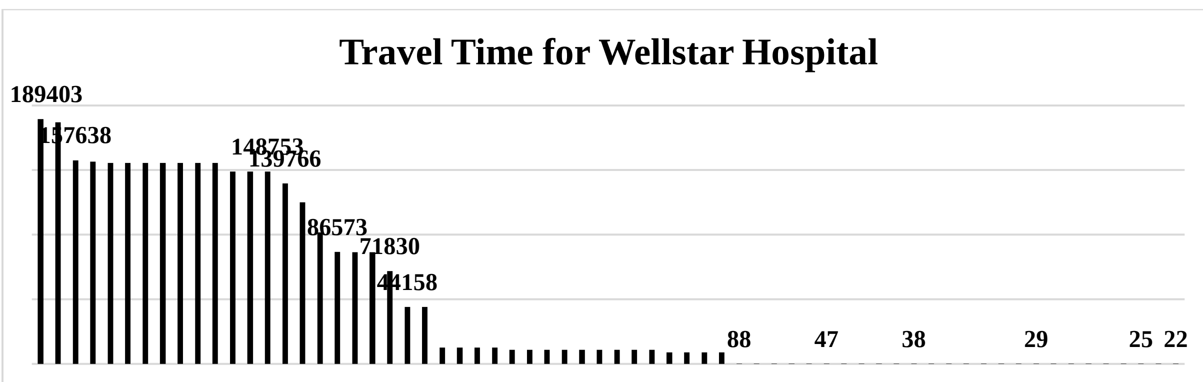

Chart 4.3.4.8: Distribution of the travel time for Wellstar hospital

Most of the selected hospitals have an accessible travel time. It takes eight minutes to travel five miles on average if the car is traveling at 35 mph. Most of these routes have a longer travel time compared to that. The Med post urgent care has the lowest spatial accessibility as most of the service area is not covered by the bus routes. For the Dekalb hospitals, the longest travel is almost 5 thousand minutes and shortest travel time is 21 minutes. The average time is 13567 minutes, and the median time is 63 minutes. Table 4.3.4.2 shows the summary of the calculated travel time. For many of the routes, the travel time is much longer than the time known as the “golden hour” so it is difficult for patients to reach these locations from these origins for emergency treatment.

4.5 Major Findings

The major findings from this case study are as follows-

- The top 300 bus stops within the disadvantaged census tracts have a lower travel time but many of the healthcare facilities are not accessible from these bus stops. So lower travel time does not mean more overall accessibility.
- 55% of the bus stops from the disadvantaged area take more than 3 hours on average to reach the heath care facilities.
- Many of the Top 100 bus stops have a very long travel time due to longer wait time and longer distance between transfers points.
- The inaccessible hospitals are mostly the same ones for bus stops with low ridership and for bus stops within the disadvantaged area.
- Most hospitals are least accessible from the MARTA stations with low ridership.
- MARTA stops with low ridership have lower percentage of transit dependent population.

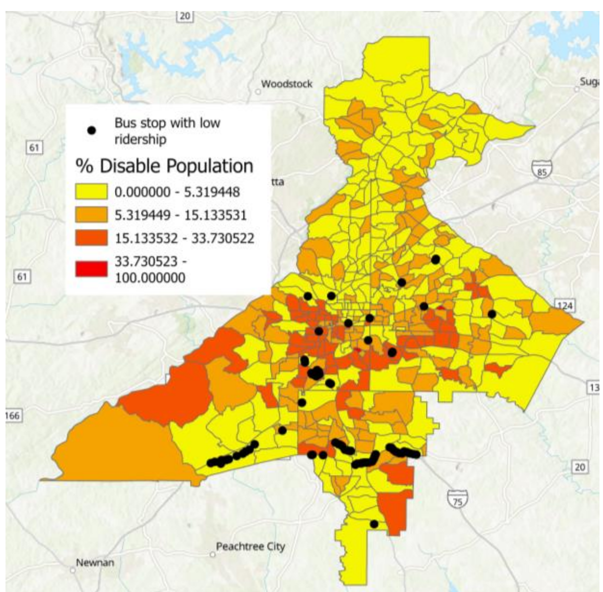

Figure 4.5.1: Percentage of disabled population

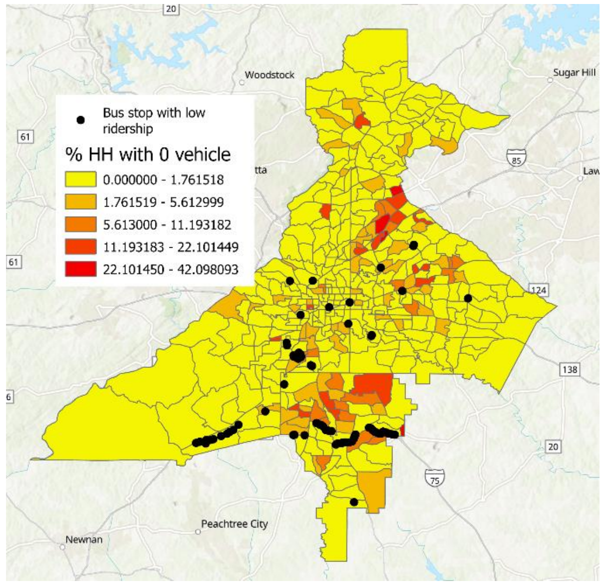

Figure 4.5.2: Percentage of HH with zero vehicles

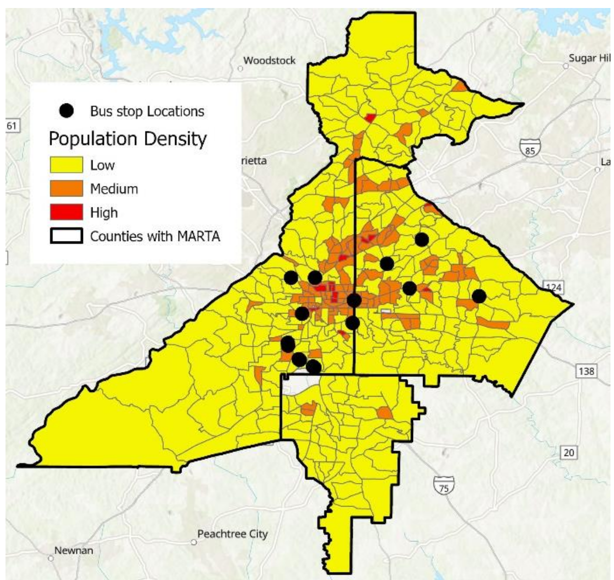

Figure 6.1.2: Locations of low ridership bus stops with an average time of more than 3 hours

CHAPTER 5: LIMITATIONS OF THE STUDY

The study has the following limitations -

- The TransitSIM model is time consuming to run which was a big factor in the analysis of this study. This could be resulted by the capacity of the computer that was used to perform the simulation run. With a more powerful computer all the stations could have been entered as the origin of the trips and more accurate results could have been generated.
- Since the destination data was collected from OSM it is possible that the data was not up-to-date and was missing a few healthcare facilities' locations or had incorrect data.
- The simulation was only run for weekdays as the scheduling is the same for all the weekdays. Due to time limit, the weekends were not included in the calculation, but hospitals and emergency cares are still open on the weekends.
- During the simulation run some errors and warning signs were generated by the Python Environment such as discrepancy in time, distance for a few trips and abnormal geometrics for a few trips.
- Sometimes unexpected issues can occur such as road closure, strike of the drivers, natural disasters and that can change the scheduling of the buses but none of that were accounted for in the TransitSIM calculations.
- Not all the routes have the same schedule, but the start time was selected as 9:00 am for all the trips.

CHAPTER 6: RECOMMENDATIONS & CONCLUSION

6.1 Recommendations:

Some of the recommendations are as follows -

Improving sidewalk network: Even though TransitSim uses the selected bus stops as the origin for the simulation it still uses all the stops of the bus route network to find the best possible routes. So, to improve the accessibility of one location it is also important to improve the overall bus route network. For all the trips to run smoothly the sidewalk network also needs to improve as well. Improving the sidewalk will help the commuters to reach the bus stops and transfer from one bus stop to another bus stop efficiently.

- Using the OpenStreetMap sidewalk network can be checked to find missing links
- SidewalkSim (similar to TransitSim but used for sidewalks) can be used to identify other barriers (road crossing, ADA accessibility) in the sidewalk network to improve the sidewalk network for better transfer.
- All the bus stops need to be ADA-accessible.

Equal distribution of healthcare facilities: Unfortunately, most of the hospitals and clinics are located outside of the disadvantaged area. To make healthcare geographically accessible it is important to have an equal distribution of the clinic and healthcare. To improve equity and to make disadvantaged areas more livable, public-private partnerships can be a great way to identify ideal locations for new healthcare facilities to minimize the gap in the health care service.

Increasing bus service: To make the bus route more accessible and equitable, areas with high ridership within the census tracts with low income and high percentage of transit-dependent people should be prioritized. More Bus stops and more frequent bus service is needed in these areas.

Analyzing unsuccessful trips: The incomplete trips need to be analyzed to understand the reason. Based on the reason for the unsuccessful trips the solutions can be provided.

- The route map can be used to identify ideal locations for transfer points and new buses can be added.
- Adding bus stops on the routes that take really long time to reach the healthcare services to minimize transfer time.

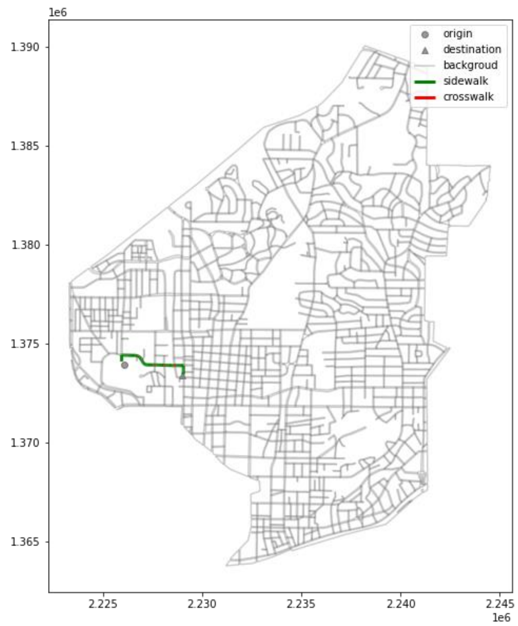

Figure 6.1.1: Sidewalk network collected from OSM

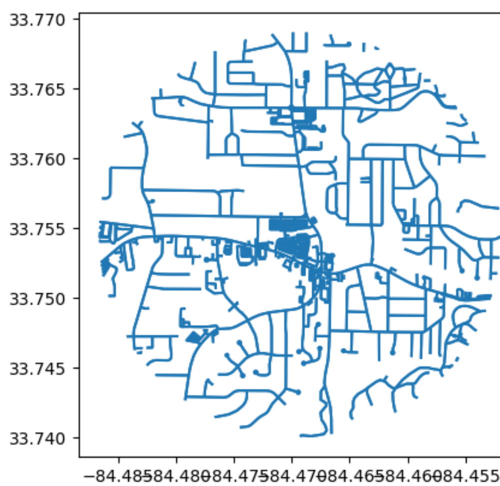

Figure 6.1.2: SidewalkSim results

In the literature review, it was found that ridership numbers can be compromised sometimes to assure accessibility and equity to transit-dependent groups. In the results of this study, it was found that in some instances the census tracts without MARTA bus service have a greater number of transit-dependent and vulnerable groups of people compared to census tracts without MARTA. Also, it was found that some stations with low ridership have a higher percentage of vulnerable groups of people. So, to make the MARTA bus service more equitable it is also important to improve the MARTA bus stops with low ridership.

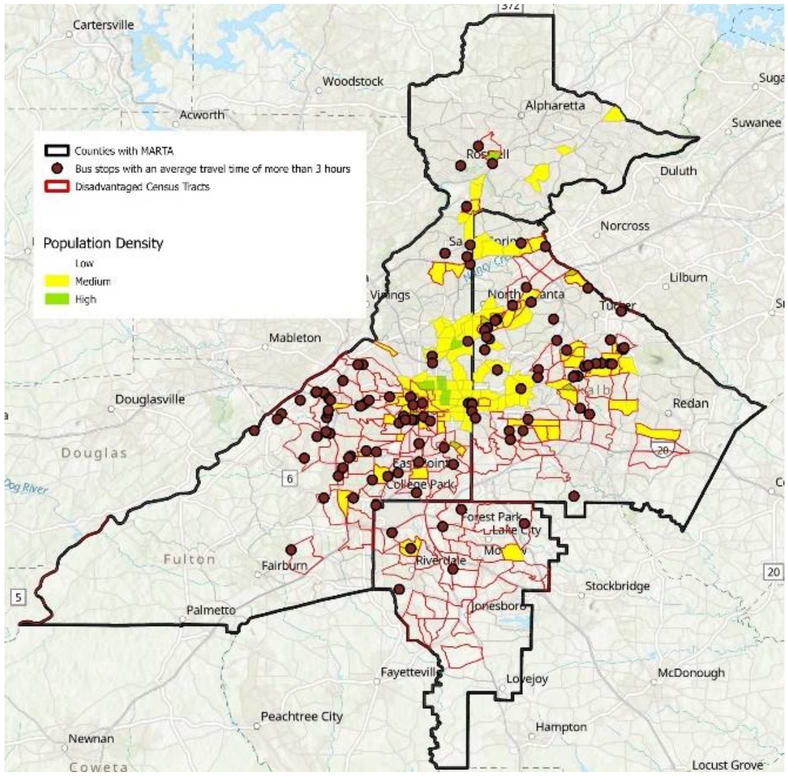

Figure 6.1.3: Bus stop locations with an average travel time of more than 3 hours

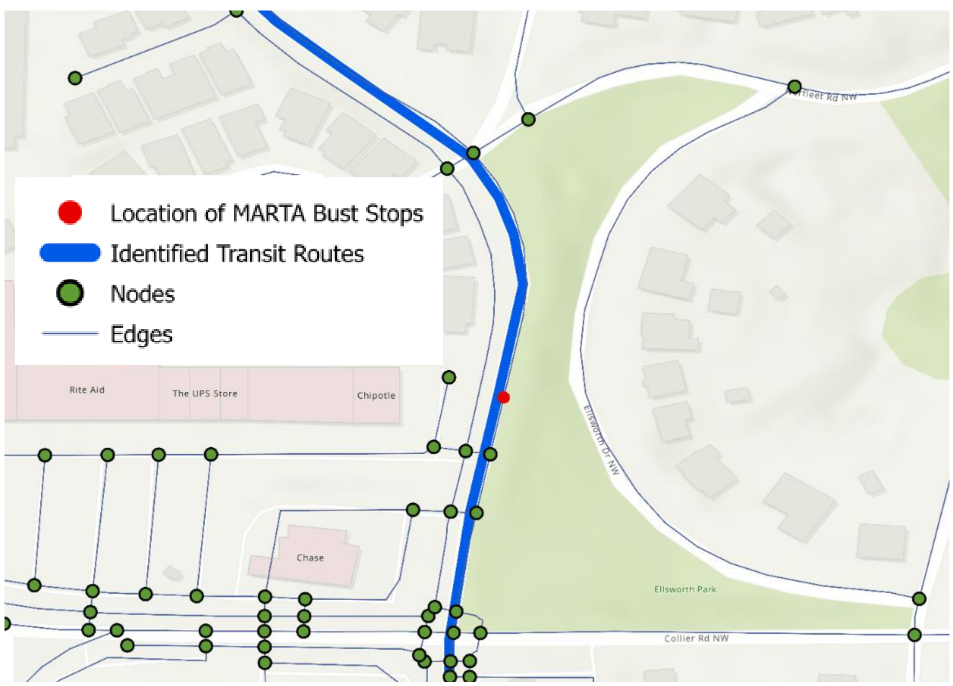

Figure 6.1.4: Section of a route map created by TransitSim

Using the output from transitSim detailed route maps can be prepared to identify the best locations for MARTA stations or to modify existing bus stop locations to make the routes more efficient. The shapefiles from transitSim can also help to identify new routes to extend the MARTA service area and to include more healthcare facilities in their service area.

6.2 Conclusion

Healthcare is a basic human right and everyone should have access to it. This study only focuses on spatial access to healthcare which is equally important as the other types of accessibility to healthcare. Reducing the travel time can help the patients to reach the healthcare facilities faster and possibly within the golden hour. Most importantly, the people who are disadvantaged and mostly dependent on public transit will significantly receive improved healthcare services. When someone is feeling unwell it might be difficult for them to drive themselves to a healthcare facility so public transit can help even patients who generally prefer to drive. A transit service with high accessibility to health will surely improve the livability of the study area. Improving the public transit accessibility to healthcare will not just improve the equity of the transit system, it will also improve the overall quality of the public transit system. The MARTA bus service has the potential to improve, and the recommendations suggested in the study can surely assist with that. The study was not able to touch on a few things that are mentioned in the limitation section of the study. Future research can investigate the issues mentioned in the limitation section and it will help to fine tune the study results of this study.

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