Evaluating System Reimagining

A Spatial Equity Survey of Houston's Transit Network

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INTRODUCTION

Buses a terrible reputation in today's society. Many complain about their slow performance and cleanliness. So much so that there are many plans for the removal of buses with the replacement of street cars. Trains are also considered to be more useful and luxurious because of their speed, dedicated right of way and capacity. But recently there has been a resurgence interest in buses. This follows from two recent developments. The first is that there was an uptick in urban population growth in the early 2000s (Urban 2018). The reason for the growth is not known but there was still a reaction. That growth rate is now decreasing but it started a conversation around urban transit that was dormant. While much of that growth is occurring in the world's biggest cities, those with populations over 10 million, the majority of the growth is happening in cities with populations of less than one million people. These cities don't have the population density or the money necessary to support heavy rail for the entire cites. They are in need of bus services that they can afford. Another reason that buses are becoming more popular and more studied is that inevitability of driverless vehicles. For bus operations the cost of the driver is often 70% of the total cost of operations (MacKechnie 2017). A future with autonomous vehicles removes these cost completely. With costs substantially lowered bus service becomes more viable for cities. This study was motivated by these two ideas and the idea that if there is going to be an increase in bus ridership it should not leave behind the people who currently use and rely on the system.

The revitalization of the cities and buses in the United States is to be celebrated but we must not forget about their storied past. Buses have served as a mechanism for the creation of equality for many years. The segregation of the Montgomery bus system and the subsequent bus boycott centered around the equitable treatment of African Americans on a system they heavily supported. In 1994 in Los Angeles a community group, called Bus Riders Union, were instrumental in the shift of transportation planning efforts from suburban rail to intercity bus service. The result was a legally binding requirement for to not only improve intercity service but also to consult the current ridership before future changes (Grengs 2017). So as buses come into prominence again this history of segregation and inequitable distribution must be a part of the discussion. Each bus study has a component of equity included, because the federal NEPA process requires it. But more than the minimum should be done. The questions of who is being served and who receives the greatest benefit of new service are important questions that must be answered.

This renewed interest has resulted in bus system redesign studies across the United States. Austin in in the process of completing a transit plan that will provide new more efficient service (Austin 2016). Seattle and Boston both studied their system in sections. The Maryland Transit Administration completed an overhaul of its entire transit system in 2015 that was not received well by the city of Baltimore (“While...” 2017). One of the most recent completed, implemented and extensive studies was the Transit System Reimagining Plan in Houston.

This study was completed by the Metropolitan Transit Authority of Harris County (METRO). METRO operates the transit system in Harris County; which contains the United States 4th largest city, Houston. In 2015 Harris County has a population of 4,356,362 people. Houston had a population of 2,217,706 people, and is one of the nation's fastest growing cities (ACS 2015). It is also the 4th largest city in the United States by land area, at 599.9 sq. miles. The Reimaging plan was lauded because it was the first time that the METRO system had been reviewed as a whole since its inception. Demographically Houston is one of the most diverse cities in the United States. As shown below there is a significant African American and Asian American population.

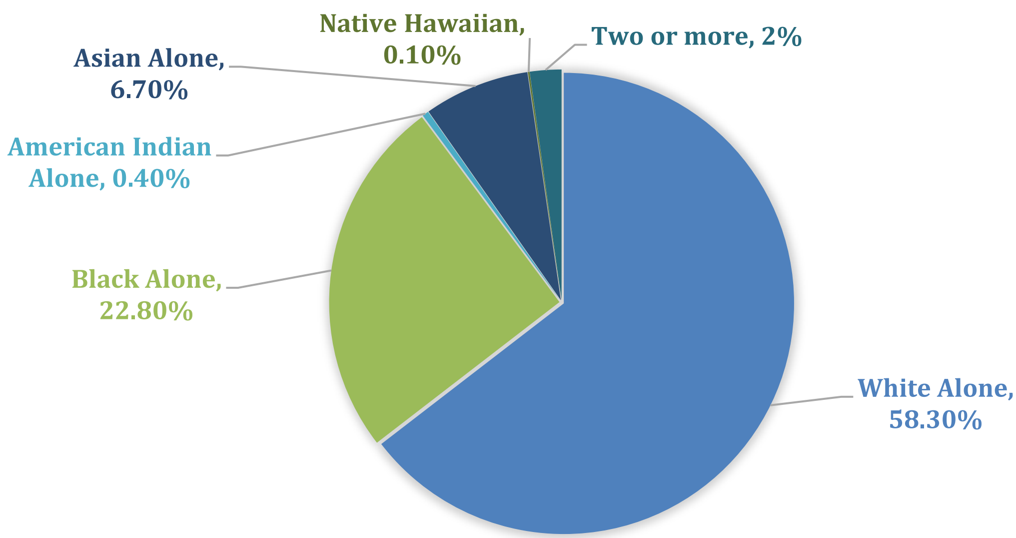

Figure 1: Demographic Breakdown of Houston

Also, 44.3 percent of the population reports being Hispanic as well with 29% of the population being born in another country (US Census 2018).

The System Reimagining Houston bus system redesign was initialed in the face of five major issues. The first was that the public requested improvements. The system carries 85 million unlinked passengers trips annually ("Factbook" 2017). During repeated public outreach the planning team received request for improvements. Many comments received expressed a desire for improved frequency, more service delivery and less complexity. Secondly, there was a decline in ridership. As ridership dropped and population increased there was the idea that there was a mismatch between the people and the places the system served. This lead to the third reason which is the fact that Houston in 2011, when the study was initiated, looked very different from Houston in the 1978, when the system was created. The population had changed as well as the principle industries driving the economy. The fourth issue was that METRO was at the time planning a new light rail system in the cities core. This addition stood to greatly change the transit landscape of Houston and therefore the entire bus system. METRO wanted to understand how the bus network could be adjusted to work best with this new investment. Lastly METRO looked at the transit in Houston and other cities similar to Houston, such as Seattle, San Antonia and Austin. There was a clear understanding that for their size and level of resources that they could do better (Reimagined 2014).

This study will analyze the accessibility of the METRO bus network before and after the System Reimaging project. The goal is twofold; the first and principal goal is to evaluate the spatial changes to the system. One of the key benefits of the holistic evaluation is that you can see where there may be large holes in the system and you can adjust the system to be more balanced. Looking at the spatial changes of the system large changes like this will be detected. The second goal of the study is to see how the spatial changes of the system effected the how equitably the system was serving the people of the Houston metropolis. For these evaluations a catchment area analysis will be utilized. The studies analysis using easily accessible data intentionally.

The hope is that the method can be easily utilized by nontechnical personal to assess transportation plans and changes.

The analysis was done largely with of an ESRI's ArcMap, a geographic information system (GIS). In particular the ArcMap network analyst tool was required to simulate the bus network and the real-world connection conditions. The R statistical language as well as RStudio (an integrated development environment), was used for all statistical analysis. These include regression analysis as well as descriptive statistics.

In order to meet the above goals and to do a proper exploration of the topic at hand, an understanding of a two topics is necessary. The first being equity of accessibility, and the second being the history of transit in Houston and the United States. Both are well studied topics and a wealth of literature has been written on their history theory.

EQUITY

Equity of accessibility is a topic that is not easily defined. There is often confusion between equality and equity. Equality is focused on provision. Equally give out resources means that everyone gets the same amount, no matter how much they started with. Where equity is outcome focused. The goal of equity is to ensure that all parties have the same result. For either measure it becomes very difficult to achieve an even outcome because there are so many dynamic factors, especially in social matters. The landscape of a city, block or individual is constantly changing and there is truly only one point of balance and an infinite points of imbalance. The author sees the role of planning to work to reach that one point, although it may be difficult and often is not obtained. Equity of accessibility is the focus of access to work, hospitals or even the city is measures and provided for in such a way as to create equal outcomes.

Inequity is often present in cases of limited resources, just like many of the problems that that planners face. In these cases if one person is to have more than another must have less. Transportation has become a prime example of this. The money that is available for transportation improvements is limited, therefore so are the plans to implement improvements. So if the government is to implement an inner-city bus program, like in LA, they would have to take that money from some other plan. When discussing accessibility then it is appropriate to use a comparative approach in order to weigh the location of the best point of balance.

In order to measure equity, one must think about comparison. For this paper the comparison will be between the people of Houston and their neighbors. Bullard calls access to transportation a “civil right” in his 2004 works, *Addressing Urban Transportation Equity in the United States*, because of how many facets of life it touches. Transportation systems, such as the bus network or highway network, are used by citizens to access jobs, to take care of family, and to access the many all that a city has to offer. Though these resources are not evenly distributed thought-out the city. Bullard discusses three major modes of disparity; spatial, procedural and social (Bullard 2004). Spatial inequity is an issue of all areas not being treated equitably. Transportation infrastructure and spending are not evenly distributed across all places geographically or demographically. Procedural inequity is present in the fact that the process decision making around transportation spending does not allow for all voices to participate evenly. In the United States the transportation spending decisions are done by legislative or executive bodies and typically do not include direct voting. Lastly the social component of inequity comes in the form of need and provision. These items are not distributed equally. A family with two cars living in the suburbs does not have the same transportation needs as a person living in a high-rise in the city. All space is not the same, and therefore should not be treated the same.

Bullard argues that much of the inequity in the United States stems from the transportation funding system. Because the bulk of transportation funding is provided by the federal government directly to the State governments for distribution. The metropolitan areas are at a disadvantage because of the three modes of equity presented. States therefore must attempt to balance the spending between the needs of the urban and rural environments, which are typically quite different. With the advent of the suburban environment this tension only increased. There are also power dynamics at play with the role that wealth plays in political decision making. As a prime example he states that national spending on transit projects since the early 1900's has been $50 billion while spending on roads have been over $200 billion (Bullard 2004). The funding for transportation is quite limited and the dedication of more resources to one has been ideologically and functional treated as the opposite of spending on the other. This is partially warranted as they both come from the same allotment of money and if you give to one you have to take from the other, but that doesn't mean they are in complete opposition. There is the option that the government add additional funding for transportation. Actually, they should be improved simultaneously in a way that provides the best possible network. They are both needed for the whole system to operate smoothly.

This idea of equity over equality is also related to the theory of utilitarianism that states that one should look to maximize utils, which are the unit that measures the happiness created by the gain of an additional unit of resource; be that money, food or any other item. The utilitarianism theory was created by Jeremy Bentham (Adler 2010). Utilitarianism asks do all people use resources the same and have the exact same needs and also answers no. Utilitarian's believe that the more resources one has the less one gains from having additional resources. A plot of resources vs happiness is logarithmic with decreased benefit for each additional unit of resource provided. This can be seen if you look at one unit of money, food, or etc. instead as a percentage of the total. For a person that has 10 dollars, a one-dollar increase is equal to a 10 percent increase. While for a person who has 100 dollars, a one-dollar increase is a 1 percent increase. The theory posits that this percentage difference is essentially equal to the difference in happiness gained. Therefore, it follows that a person who is already high on the curve benefits less from an additional unit of resource than the person lower on the curve. Utilitarianism also states that it should be the goal of a society to maximize happiness. So, it supports more units going to the poor in order to increase overall happiness. The connects to equity because it again shows that all people are not starting from the same position and therefore have to be treated differently to get to the goal of equal distribution.

In terms of transportation the resources that is being provided is access. Access to work or to movement as a whole. In the United States the person who lives in the suburbs with two cars has much more access, measured by how much space you can reach in a given time, than the person in the high-rise in the city. The person in the city may have access to more by just walking than the person in the suburbs but there is a theoretical limit on how far one can walk in a set period of time and overall, and it is much less than the distance that one can drive in that same amount of time. Additionally, policies in cities in the United States have led to situations where the cities have come to lack a full spectrum of employment opportunities and mechanisms for economic development. Because of the spatial difference between the city and the suburbs they have become aligned with highways and transit, respectively. Highways allow suburban dwellers to travel between their homes and central business district, where they work, quickly and efficiently. Transit allows the city dwellers to access all that the city has to offer without the need for an automobile.

This ties back to the study of Houston because it is this very social component of inequity that the authors study aims to measure. It is important that when studying transportation projects that we look at who that transportation ultimately serves. Some planning theorist believe the goal of transportation planning should be to serve people according to their needs, with a focus on the outcomes. All should be able to get where they need to go in a reasonable timeframe. This is not the only goal of transportation, but it is a primary one. Though the measurement of space, time and people this study will look at the Houston METRO network and try to provide a better understanding of its level of equality in 2011 and 2016.

HISTORY OF TRANSIT IN THE UNITED STATES

In order to have a discussion on transportation equity in the Houston it is necessary to have an understanding of the history of the United States personal transportation system, with special attention to its two main components mass transit and automobiles. Personal transportation in the United States is often broken down into four time periods; the first was the Walking/Horse period (1800-1890), the second was the Streetcar/Omnibus period (1890-1920), the third was the Introductory Automobile period (1920-1945) and the last is the Freeway period (1945 to now) (Griffin, 2006; Adams, 1970). Some argue that the freeway period is ending with the move back to cities and horizon of autonomous vehicles, but currently the majority of travel still happens in non-autonomous vehicles on the highway.

Mass transit began during the first period, along with the roadway network; although they both looked quite different than they do today. The first transit routes in the United States were horse drawn omnibus routes in the east coast cities of Philadelphia, Boston and New York City. Many of them started in the early 19^{th} century. During this period, the government participation in transportation was none existent. These routes and roads were privately funded and operated. At that time the cities were growing and full of industry, commerce and people. They represented very dense and mixed used places, but not in the nice way we think of today. They were dirty and overcrowded. People needed to live near the places they worked because their main mode of transportation was walking. It made sense to minimize the distance they needed to walk each day. The early omnibus routes were in fact used mainly by wealthier individuals. Those individuals were able to afford the cost of the omnibus ride. They also were less likely to need to work in the factors or ports like others and could afford bigger homes on the outskirts of the city. But as the populations began to grow transportation access became even more important for the workings of the city.

Toward the end of the 19th century the super dense conditions in cities gained public attention. New rules were put in place that limited the density of housing, changed labor relations and provided for better living and working conditions. With these changes people started to move further away from their places of work and have more income. While living further away they still mainly worked in the city. The omnibus lines, were perfectly situated to provide transportation from the outskirts to the city. Mass transit was born, in the form of the omnibus and then the streetcar (Griffin 2006).

With the increased growth of city extents, there was an increased growth of intra-city and inner-city streetcar networks. This would be greatly changed by the automobile. Early automobiles were very expensive to make and therefore very expensive to own. Henry Ford's assembly line technology greatly reduces the cost of construction and therefore the cost of purchase. This signals the beginning of the decline in streetcar usage. The movement from the Recreational Automobile period to the Highway period was greatly aided by federal subsidies into the interstate highway system. The interstate highway system finalized the decline of the mass transit period in the United States, along with the automotive industry. The Federal-Aid Highway act was signed in 1952. This act was the first to provide funding for the United States Interstate highway system. This was a solidification of the federal government's role in providing navigable roads. Transit would not be treated in a similar fashion until the 1970s.

This has only grown with continued disproportionate funding between the maintenance and expansion of rail and of the highway network. These issues are central to the discussion of suburban and urban growth in the United States and across the world. As highway are increasingly becoming congested and people are moving back to cities there are important decisions that are needed to increase efficiency and avoid gridlock.

TRANSIT HISTORY IN HOUSTON

Transportation is Houston has a similar history to that of the United States. Transportation had its beginnings in walking or animal mobility methods. The roads and train tracks were nonexistent. Houston was not a very populated place in its early year. It was founded in 1836 by two brother, Augustus Allen and John Allen from New York (“Houston” 2018). It was a town of business people who were looking to capitalize off of the trade that was happening in the city. But it was also on the frontier and settled much later than the cities in the Northeast. Rail was not developed in Houston until the second half of the 19th century. Once this system started too grown so did the street car network. This network expanded greatly and allowed for development further away for the central downtown district. These networks were privately operated. This service peaked in rider ship in the 1920s. The decline was greatly correlated with the rise of the automobile. Then came the highway building which was funded by multiple levels of government. Bus service replaced many of the street car lines because of their flexibility, but these services began to lose money. Therefore they were taken over by the municipal government in the 1970s. The regional transit body, the Metropolitan Transit Authority of Harris County, was not created until 1978 (Griffin 2004).

THE SYSTEM REIMAGINING PROGRAM

The System Reimagining program was one of the many recent studies into how to reinvigorate an ailing bus system. Many of the bus systems in the United States are facing declining ridership. They are also looking for ways to carry more passengers with little or no increases in spending. City dwellers are weary of these programs because in the past larger governmentally implemented transportation programs have left neighborhood devastated. The scars of urban renewal in the form of highways is still present in many communities. The planning process was therefore carried out with ample community information sharing and engagement.

The System Reimagining plan was developed with the goal of maintaining access for all current riders. The plan development was designed with the intention that 80% of the resources would be focused on maximizing ridership and 20% would be focused on maximizing coverage. This exemplifies the equity vs equality dichotomy from earlier. Ridership is as outcome while coverage is a precondition. The heavier focus on the outcome of ridership shows an intention toward increasing equity in transportation. This is done by prioritizing more streamlined efficient routing, that will serve more people, over ensuring that all areas of the city are within walking distance to a bus stop. Because there are limited resources and maximizing both of those goals can be difficult, this has been is a common theme in recent bus network design. This guideline could severely change the transit equity in Houston. Optimization often focuses less on need and more on capital. Many recent commuter rail improvements have been targeted at increasing access to young wealthier populations and not to the current riders. It is important that all groups be accounted for and served.

The process started with a thorough existing conditions report. The planners at METRO looked at what routes were growing in ridership and which routes were not. The report also collected demographic data on the city of Houston, Harris County and the METRO operation area. They used data about ridership and also created an employment vs jobs matrix that was used to map the city. This map was ultimately used as a base map for the high-level design of the network. This network drawing was done during a weekend work shop, Core Planning. From this process an “abstracted” network was created. This network was detailed out and shown to the public and political stakeholder after this session (METRO 2013).

CURRENT WORK

The implementation of the System Reimagining plan was completed in 2015. There has not been extensive research done into the distribution of or access to the network. The METRO system presents an interesting subject for study because of its size and density. Houston’s unique regulatory structure around zoning and extensive growth make it prime place for study. Houston population of 2,217,706 is spread over 599.59 sq. miles. In comparison Brooklyn has a population of 2,629,150 spread over only 71 sq. miles.

The Houston METRO transit system is quite young in comparison to many of the other transit systems in the most populated cities in the United States. The bus system carries over 200,000 passengers per day which makes it the 16th most used bus system in the United States. The METRO system has the 9th highest average weekday ridership (“Factbook” 2016). They offers 5 major services. Their bus service carries the majority of passengers. The second most used service is the METRORail which includes 3 light rail lines. METROLift is their paratransit service which provides free service for those who cannot ride the normal buses. METRO also operates the HOV/TOLL lanes on a number of highways around the region. Some of the bus services are designated express buses from suburban park and rides to the inner city (METRO 2018).

PREVIOUS LITERATURE

There are many studies that examine bus networks. Many of them focus on the design and efficiency. These are mainly works of mathematics and geography. Another branch looks at the equitable distribution of these networks. The increase in speed and processing power of GIS software has allowed the tool to be used in spatially evaluating the equity of existing and future networks. One such paper uses GIS and spatial ranking to create a heat map of transportation access in Melbourne Australia (Currie 2009). Other papers explore cases across the world and seek to define different methodologies for evaluation and improved calculation of true equity. Because of the newness of the METRO and the system in Houston, as well as the small percentage of the overall mobility that it provides in Houston, there has been little study in academic literature of the Reimagining project or the METRO network. Most of the evaluations of the systems performance have been from a journalistic perspective.

There were two studies done that directly addressed the change in access to accessibility in Houston around the System Reimagining campaign. J. Pritchard, from the University of Texas, provided a before and after analysis of the plan. His work, completed in 2015, aims to understand the changes to accessibility that were associated with the updated network layout. The study creates a ¼ a mile buffer around the transit network. Then it dissolves census data into that buffer. This is done for both the network prior to the plans implementation and the updated network. A comparison is then made of the demographic changes between the old network buffer and the new network buffer. Pritchard does this analysis for the whole network and then separately for the frequent route networks, and the weekend network. At the time of this study, the program was not fully implemented. As a consequence, the exact locations of the bus stops were not known. By Pritchard's own admission this prevented him from doing a GIS network analysis that would have been more appropriate. The study used 5-year census data as the representation of demographic information. The comparisons were made based upon a singular data set.

The study would be improved by looking at the locations of the bus stops instead of the routes. The bus stops could be used to define a catchment area that is more representative of access to the network; because access to the bus network is not continuous but must happen at discrete points. This way difference can be determined both spatially and demographically. Additionally, having the location of the bus stops allows for a service areas analysis to be performed with the ESRI network analysis tool. The author's study looks to improve upon Pritchard's by using the exact locations of the bus stops and network analysis. Also, while Pritchard provided a comparison across gender, race, and age group this was done based upon changes in the buffer of the whole system and it was not tested for statistical significance difference at each stop across time. The author's study will improve upon this by exploring the statistical difference between each bus stop.

The second study was completed by Chelsey Palmateer, Alireza Ermagun, Andrew Owen, and David Levinson. The study looked at the Houston bus network at three-time points. The first before the System Reimagining program was initiated, one after a new METRORail line opened, and the final one after the System Reimagining plan was implemented. This study used the general transit feed specification (GTFS) to create the GIS networks at each time point. Similar to Pritchard's study this study used a buffer around the network, but the analysis added the bus stops to the network. This allowed for a deeper understanding of the changes to the network that occurred between the three different time points. An analysis, similar to that of Prichard was done, of demographics, including dissolving census data from the American Community Survey (ACS) and Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES) data sets into the buffers.

The Palmateer study was limited in that it only analyzed total population and total number of jobs. In the study the buffer distances were varied, between 2700 ft. and 16,400 ft., in an attempt to determine if this changed the number of jobs that were accessible within a fixed time period. The results showed little influence of the size of the buffer on the percentage change in the number of jobs that were accessible from one area. Essentially the buffer distance is not that important when comparing changes across time as long as it is at the same location. But the study did show that if you were to compare different locations that the size of the buffer did matter. A combination of the finer location data associated with the Palmateer study and the demographic analysis included in the Pritchard study would make for a more complete analysis of how effective the System Reimagining plan was at creating a more equitable network and at serving its current users.

This paper provides a deeper analysis of the Houston METRO system than has previously been completed. Houston is a growing metropolis and as even bigger cities, such as New York City and Los Angeles, are studying bus network redesigns Houston provide a prime case study for the redesign process. As a response to the long history of transit network inequity it is important to know if the outcomes and methods of the Houston redesign were effective and how they might be improved. This study provides another metric for measuring equity that synthesizes current practices and builds upon them through the use of open regularly updated data from the ACS.

PURPOSE STATEMENT

This thesis proposes a study is the equity of accessibility of the METRO transit network. The study will analyze the network at two-time points--before System Reimagining (2011), and after System Reimagining (2016) --for a comparison of their accessibility. This comparison will be accomplished through the use of GIS network analysis. Data will be obtained from the US Census Bureau ACS survey, US Census Bureau LEHD LODES, Harris County shapefiles and METRO GTFS releases.

RESEARCH QUESTION

What were the effects of the METRO System Reimaging bus network redesign on the accessibility of the Houston bus network? The draft System Reimagining report states that it kept coverage of “essentially all” of its existing customers while increasing access. Their focus on maintaining access to current riders while building their network accessibility creates a situation where there is a possibility for inequity to develop. The plan articulates an 80% focus on ridership and a 20% focus on coverage. The large focus on ridership leads to a hypothesis that there will be an increase in network equity.

METHODOLOGY

PARTICIPANTS

The Harris County Regional Transit Authority created a quasi-experimental analysis point by holistically studying, and then implementing, a new bus network. They created a situation where one day the people of Houston were living in one condition and the next day they were living in a new condition. The quasi-experiment allows for a two-point time series analysis of the differences between the bus networks in the METRO service area. This area included 8 counties (Harris, Fort Bend, Galveston, Brazona, Waller, Montgomery, Liberty and Chambers), henceforth to be called the **STUDY AREA**. For this analysis the people living in the **STUDY AREA** are all anonymous participants. At each time period the level of equity of accessibility will be assessed.

METHODS

The study explores how effective the System Reimagining program was at increasing accessibility to residents of the Houston metropolitan region. Access can be defined as “freedom or ability to obtain or make use of a good or service.” For this study access was operationalized as the total area that can be reached in a fixed amount of time, while traveling on the METRO bus network and only changing buses at bus stops. Measuring accessibility as area is a common metric for transportation studies. This was seen in both the Pritchard and Palmateer studies.

Harris County METRO provides both GTFS and ESRI shapefiles for their transit routes. The GTFS file contains mainly transit scheduling and location data but the ESRI shape file contains much more information about the route. It provides the stop location, cross street, routes served and other valuable information. These shapefiles were the starting point for this analysis not only because of their nativity to ESRI ArcGIS but because of the plethora of data included with them. The study considers access for a group that is defined by a service area created around each bus stop in the METRO bus network.

These areas will be defined based upon a standard walking distance of one quarter of a mile or 1320 ft; henceforth referred to as the **BUS STOP BUFFER**. A walking buffer is regularly used to represent all of the individuals who have reasonable access to a transit facility. They are often used to explore the accessibility at a walking distance of ¼ of a mile. This distance is considered a comfortable walking distance. In the particular case of Houston, the combination of all of the quarter mile walk buffers from each bus stop represented a somewhat continuous but not full comprehensive coverage of the city

Figure 2: METRO 1320' Bus Stop Buffers (2011)

Figure 3: METRO 1320' Bus Stop Buffers (2016)

A pedestrian walking network service analysis was considered but because the demographic data that was being used was at the census tract level and not the lot level a simple circular buffer was chosen. Attempting to disaggregate the data from the census tract to a network service area based upon area alone, without any additional information such as location of residential unit, would lend itself to distortion. There would be population attributed to locations were they are not and it would not provide any real additional information. Additionally, this thesis's analysis is meant to look at the potential pool of transit users at each stop and how the process dealt with balancing the ridership vs access problem for those potential riders. The pedestrian service areas would be more beneficial for a finer analysis. One such as addressing issues of equity at each bus stop instead of across the city. Lastly the Houston city fabric also is more porous than many other cities of similar population due to its lower density. Therefore, the street network is not as representative of the way that pedestrians access bus stops. People may walk across many other open areas. The circular buffer is a better representation.

In this thesis's analysis the bus stops were then used as the starting facilities for a service area analysis along the METRO bus network. A half hour was used as the time limit for movement along the network. The half hour time frame was combined with bus speed of 20 miles per hour to obtain a service area line along the network. Additional variability would have been included if the individual bus headways or actual speeds were utilized. For this study it was found best to work with time as a constant, not as a variable, in order to establish a baseline measure of equity. Future work should take into account the speed differences. The baseline measure will be useful in discussion of accessibility from the perspective of the planning process of the redesign. Because consistency is provided by assuming a constant speed across the entire network because that is the assumption from the study. It is clear to the author that this is far from the reality and lived experience of the people in the STUDY AREA. This method provides a way of isolating the effects of the routes changes on accessibility.

The network analysis tool also allows for the definition of an impedance measure along that network. Typically, this is defined as length but could also be defined as other things such as time or capacity. For this particular analysis the routes had to be split at the transfer bus stops and each put into their own feature class. The individual bus routes needed to be split at these stops in order to mimic the real-world transfer conditions. These conditions allow only the transfer from one bus line to another at the stops. Length was set up as the impedance measure, knowing that speed and time would both be constant, a constant distance could be determined for each service area analysis. After splitting the routes, they were then added to the ArcGIS network dataset along with the transfer stations.

For the network analysis, only certain bus stops were used to create the network analysis layer. The bus stops that were included in the network were the ones that served more than one route. The assumption was that if a person were to get off at a stop that serves only one route then you can only get back on that one route, they cannot transfer to any other route and therefore cannot have a new branch to the service area tree. The stops in the network serve as the only points of transfer in the system. The default network layer created by ESRI's tool creates transfer relationship by lines that cross or that have vertices that meet. But that is not how a true bus network works. Riders cannot get off or on the bus at any location along the route or when it crosses another bus line, only at the bus stops. Of the 10,098 bus stops in 2011 only 2110 stops served more than one route. For 2016 only 1574 of the 9004 total stops served more than one route. With these stops and the routes, the network was created.

The Network Analyst tool created a network feature data set which consists of all of the edges in the network and all of the junctions connecting those edges. Once this dataset is established then an analysis layer must be established. A service area layer was established as the analysis layer. In this layer some facilities must be included as a seed for the analysis. Additional features can be added as blockages including lines or polygons.

The output of the network analysis was a collection of polyline features, one for every bus stop. They represented all the possible movements that could be made along the network from each bus facility, in a half hour. But the lines could not be buffered for a walk distance because they did not truly represent the accessibility. Also, since the bus stops are not directly on the line, because the line runs down the street and the bus stop are on the sidewalk, a 100' search tolerance was used to ensure all of the bus stops were captured. Therefore, each line was used to identify the bus stops along it, and those bus stops were then used to create another buffer area, henceforth called the **BUS STOP SERVICE AREA**. This area was much larger than the **BUS STOP BUFFER**, because for each facility there were many other bus stops that it connected to through the network. A 1320' ft. buffer around each stop was merged into one feature class. The buffer represents a collection of all of the places that one could go along a bus route in a half hour. These areas collectively made up the data set for the regression analysis.

Because of the large number of stops a sample was required. ArcGIS has a tool called Subset which allows a sample of features in a feature class to be randomly taken and assigned to a new feature class. This tool was used to take a sample of the total number of stops for the analysis. GIS was also used to provide areas, length and other spatial measures for all features classes.

OnTheMap is an interactive tool provide by the US Census Bureau that provides a graphical user interface for interacting with the Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics data set, known as LEHD LODES. This data set is produced by combining employment data from multiple public administration levels. States provide unemployment insurance earning data as well as other administrative data which is combined with other national census and survey data. The data is anonymized at the census block level to produce a rich display of nearly every job in the United States of America. Each job site is geo-located and the number of jobs at that site are categorized based on the North American Industry Classification System. The NAICS code system classifies business into one of 20 categories. There are further divisions but the LODES data only includes 20 sectors. The jobs in each sector are assigned as an attribute of the census tract feature. The jobs within in a 10 mile buffer of Harris County were obtained, in order to cover the entire METRO service area. As expected, many of the jobs are clustered around the highways and downtown district in Houston.

Once both the BUS STOP BUFFER and the BUS STOP SERVICE AREA were obtained then the census data was proportionally split and added to each of these areas. The census data is provided by the Census Bureau in tabular format. Each line from the table was joined to the feature class of census tract polygon features for all census tracts in the STUDY AREA. Eight total census measures were chosen.

Table	Variable
B01003 Total Population	**Total Population**
B11001 House Type	**Total Number of Households**
B11001 House Type	**Total Households with a Female Householder with No Husband**
B19013 Median Household Income	**Median Household Income**
B25035 Median Year Structure Built	**Median Year Constructed**
B25003 Tenure	**Total Number of Owner Occupied Households**
B25003 Tenure	**Total Number of Renter Occupied Households**
B25003A Tenure White Alone	**Total Number of Households that are White Alone**

Table 1: Demographic Variables Utilized

The specific variables were chosen in order to highlight groups that are typically disproportionately served. Total population and number of households are used to explore how many people the system is actual serving and also to provide normalization for other variables. Median income serves as proxy for how much wealth effects the treatment in society. Building age and tenure were included as a social economic measure. New buildings and owner occupied units are often representative of new wealthier residents. White alone was included as proxy for race. The study used this variable to see if there was differences of the provided service by race. Lastly the Female head of household was used as a proxy for non-traditional families.

Census data for this analysis was obtained from the 2015 ACS 5-year estimate. This was because while the 3-year and 1-year estimates provide data at the census tract level, they contain a high margin of error due to the limited sample size. And while the 2011 ACS 5-year estimate would have included data wholly before the System Reimagining implementation, the 2016 ACS 5 year data would have included data from before the implementation and after the implementation. Therefore, there could not be a true comparison of the difference in demographics before and after the change.

Similarly, to the constant bus speed of 20 miles per hour, it was decided that there would be a constant demographic dataset used for both time points. Additional study is warranted once the appropriate data is available to see the impact on the city in the face of the system changes. These values were used as the independent variables in the regression analysis of the bus stop buffered areas but also were used in the descriptive analysis of the BUS STOP BUFFER and SERVICE AREA. Total area for each BUS ROUTE SERVICE AREA is the primary dependent variable. Independent variables included the census demographics in each BUS STOP BUFFER.

These variables were selected because they offer a glimpse of the real reasons that the study of equity of access is needed for everyday life. This study aims to not only statistically answer the question of equity but also to provide metrics for what equity looks like on the ground for day to day activity.

Judgement of the differences between multiple service areas can be determined in many ways. For this study a multiple variable regression was utilized. This disclosed relationships between an increase in the travel distance and a change in the many independent variables. Variability in the set of independent variables was also considered. All of the variables act on different scales. Therefore, it will be useful to see the distribution within each variable. As a measure of practicality and implementation one composite measure was provided to highlights global difference, this is the regression.

DISCUSSION

DESCRIPTIVE STATISTICS

Descriptive statistics are utilized to provide a more precise description of the form of a data point or data set. The initial exploration of the results of the network analysis looked at the shapes of the resultant areas. Considering how much of the STUDY AREA that citizens from given a BUS STOP BUFFER have access too, there was a decrease. The minimum and maximum both decreased as did all the intermediary statistics.

2011 SHAPE AREA area Summary (sq. mi.)					
Min	1st Qu.	Median	Mean	3rd Qu.	Max.
1.16	60.32	91.06	90.29	123.65	167.25

Table 2: Shape Area, Summary Statistics (2011)

2016 SHAPE AREA area Summary (sq. mi.)					
Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
1.00	44.04	71.03	71.54	100.81	144.46

Table 3: Shape Area, Summary Statistics (2016)

This drop at first may seem in opposition to the original hypothesis put forth in this paper and also by the METRO planning team, because it would seem to limit the number of people that have access to the system. But this is not necessarily the case. The population location could have changed quite substantially from when the system was designed and the old system may have been severing areas that really were not where people were living. As part of the redesign the system could have just been made more efficient. In terms of comparison to the STUDY AREA, which has a total area of 108 sq. mi. of water and 708 sq. mi. of land, the maximum value of any one SERVICE AREA is small. The total area of the city of Houston is 600 sq. mi.

Additionally, histograms for the 2011 areas and the 2016 areas were calculated.

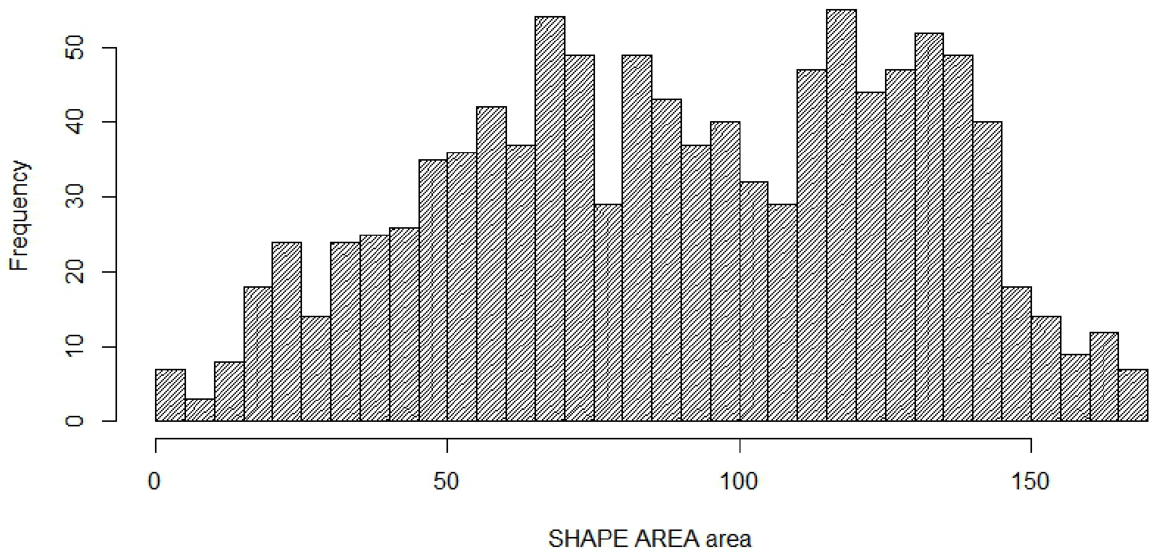

Figure 4: Shape Area area (sq. mi) Histogram (2011)

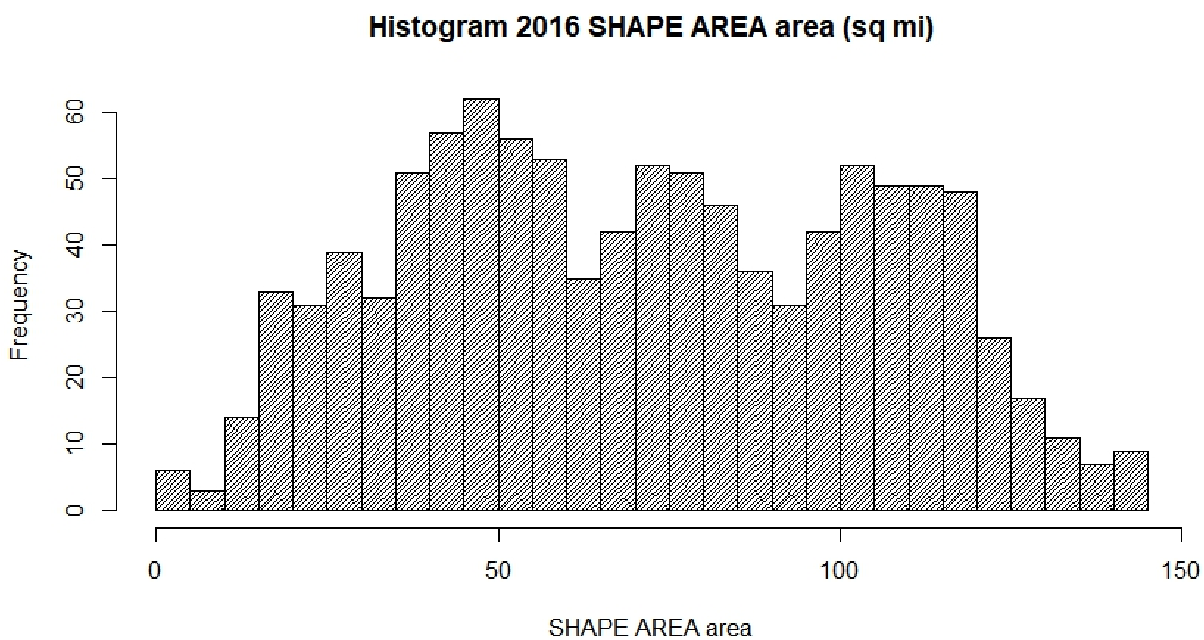

Figure 5: Shape Area area (sq. mi) Histogram (2016)

The histograms show that there is a change between 2011 and 2016. In 2011 the SERVICE AREAs tend to be more skewed toward larger areas. This changed in 2016 with a less skewed distribution, although still not normal.

INFERENTIAL STATISTICS

For a deeper understanding of the changes that occurred between 2011 and 2016 inferential statistics were included in the analysis. Inferential statics take into account the probability of occurrence of a set of circumstances to start to determine if one variable is changing another. Total accessible area was summarized in the previous section. For the regression multiple variable combinations were explored. The dependent variable in all analysis was the SERVICE AREA area, with varying independent variables. Regressions outcomes are listed below.

Significance Codes	
Level	Code
<0.0001	***
0.001	**
0.01	*
0.05	.
0.1	

Table 4: Significance Codes

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)	SI Code
(Intercept)	2,118,082,825	60,659,138.00	34.918	0.000	***
HH w/ White population alone	**1,847,645**	**252,984.00**	**7.303**	**0.000**	*******
Renter Occupied Units	-306,342	197,558.00	-1.551	0.121	

Multiple	R-squared:	0.0628
Adjusted	R-squared:	0.0610

Table 5: SERVICE AREA area = HH White Alone + Renter Occupied (2011)

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)	SI Code
(Intercept)	1,580,943,657	44,665,359.00	35.395	0.000	***
HH w/ White population alone	**2,362,275**	**197,102.00**	**11.985**	**0.000**	***
Renter Occupied Units	**-662,490**	**177,942.00**	**-3.723**	**0.000**	***

Multiple	R-squared:	0.1522
Adjusted	R-squared:	0.1505

Table 6: SERVICE AREA area = HH White Alone + Renter Occupied (2016)

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	117.63	10.88	10.810	0.000***
HH w/ White population alone	**0.07**	**0.02**	**4.441**	**0.000*****
Renter Occupied Units	-3.71	1.41	-2.628	0.009**
Owner Occupied Units	-3.76	1.41	-2.662	0.008**
Median Household Income	0.00	0.00	-0.505	0.613
Median Year Structure Built	-0.01	0.01	-2.807	0.005**
HH with Female Householder	-0.07	0.06	-1.041	0.298
Total Population	-0.02	0.01	-2.475	0.013*
Total Households	3.74	1.41	2.649	0.008**

Multiple	R-squared:	0.1015
Adjusted	R-squared:	0.09465

Table 7: SERVICE AREA area = HH White Alone + Renter Occupied + Owner Occupied + Median income + Median Year Built + Female Householder + Total Population + Total Households (2011).

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	90.27	9.82	9.189	0.000***
HH w/ White population alone	**0.06**	**0.01**	**4.229**	**0.000*****
Renter Occupied Units	-1.15	1.08	-1.059	0.290
Owner Occupied Units	-1.18	1.08	-1.094	0.274
Median Household Income	0.00	0.00	1.162	0.246
Median Year Structure Built	-0.01	0.00	-2.270	0.023*
HH with Female Householder	**-0.20**	**0.05**	**-4.046**	**0.000*****
Total Population	-0.01	0.01	-1.493	0.136
Total Households	1.18	1.08	1.088	0.277

Multiple	R-squared:	0.2177
Adjusted	R-squared:	0.2116

Figure 6: SERVICE AREA area = HH White Alone + Renter Occupied + Owner Occupied + Median income + Median Year Built + Female Householder + Total Population + Total Households (2016)

The regression analysis reveals that there were significant changes between 2011 and 2016. The two-variable regression equation presented statistical significance for the number of Households with White Alone populations at the 0.001 significance level. The positive coefficient suggests that BUS STOP BUFFERs with significantly more white households were more likely to have larger access to the city. In 2016 this was also true, as well as the significance of the number of Renter Occupied units. With the renter occupied units the coefficient was negative suggesting that the more renters that occupied a BUS STOP BUFFER the less areas that was accessible along the network. This is a disappointing correlation to find when the system redesigned was designed for increasing access to individuals. Further analysis would be needed to determine if it was true that people in renter occupied units in fact rely on the bus system more.

The multiple regression using eight independent variables presented somewhat alternative results. In 2011 white households alone was the only variable with significance at the 0.0001 level. While the number of renter occupied units, owner occupied units, median year built, and total number of households held significance at the 0.001 level. In 2016 there were only two variables with 0.001 or high significance, they were White Alone Households and Female Householders with no husband. This shows a change in the system that is not so easily explained. While the system became more equal on three metrics it decreased in equality on one metric.

Overall the changes in the system appeared to better serve many communities across the STUDY AREA. This speaks largely in favor of the methods and techniques of the System Reimagining campaign. While accounting for more than 20% of the variability in the area there is significance in the results. There are also a number of other in things that could cause the change in area.

In an attempt to see if there was some interaction between the independent variables and the year of the study the data sets were combined and the dummy variable for year was added. The regression results are as follows:

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)	SI Code
(Intercept)	113.20	7.49	15.120	0.000	***
HH w/ White population alone	0.06	0.01	5.553	0.000	***
Interaction Variable	-18.71	2.57	-7.289	0.000	***
Renter Occupied Units	-2.24	0.89	-2.535	0.011	*
Owner Occupied Units	-2.29	0.89	-2.584	0.010	**
HH with Female Householder	-0.14	0.04	-3.434	0.001	***
Total Households	2.27	0.89	2.569	0.010	*
Total Population	-0.01	0.00	-2.684	0.007	**

Median Household Income	0.00	0.00	0.384	0.701	
Median Year Structure Built	-0.01	0.00	-3.598	0.000	***
HH White Alone x Interaction Variable	0.00	0.01	0.416	0.678	

Multiple	R-squared:	0.1985
Adjusted	R-squared:	0.1947

Table 8: SERVICE AREA area = Female Householder + Renter Occupied + Owner Occupied + Median income + Median Year Built + Female Householder + Total Population + Total Households + HH White Alone x INT Year

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)	SI Code
(Intercept)	106.15	7.39	14.354	0.000	***
HH w/ White population alone	0.11	0.01	8.268	0.000	***
HH with Female Householder	-0.03	0.04	-0.617	0.537	
Renter Occupied Units	-2.10	0.88	-2.392	0.017	*
Owner Occupied Units	-2.18	0.88	-2.482	0.013	*
Interaction Variable	-17.65	1.47	-11.991	0.000	***
Total Households	2.12	0.88	2.409	0.016	*
Total Population	0.00	0.00	-0.703	0.482	
Median Household Income	0.00	0.00	0.680	0.497	
Median Year Structure Built	-0.01	0.00	-3.790	0.000	***
HH FM x Interaction Variable	0.00	0.00	-5.479	0.000	***

Multiple	R-squared:	0.2098
Adjusted	R-squared:	0.206

Table 9: SERVICE AREA area = HH White Alone + Renter Occupied + Owner Occupied + Median income + Median Year Built + Female Householder + Total Population + Total Households + Female Householder x INT Year

Two interaction regressions were completed. One attempted to look at the relationship between White Alone households over time and the other at the relationship between the number of Female Householders and time. The first proved to be insignificant but the second was significant. Reinforcing the conclusion from the earlier models that there was a significant change for households with female householders between 2011 and 2016. Additional study should be done in order to see how these households changed between the two time periods and how this relates to individual experiences in the STUDY AREA.

As a check the diagnostics on the regression the Variance Inflation Factor (VIF) was measured for all of the variables. It was determined that there were issues with collinearity.

VIF	Variables
1.28	Shape Area
26.57	HH w/ White population alone
215557.27	Renter Occupied Units
35946.96	Owner Occupied Units
14.50	HH with Female Householder
260546.32	Total Households
10.04	Total Population
2.43	Median Household Income
1.12	Median Year Structure Built
1.10	Time Period
Infinite	HHWA (normalized)
14645.99	RO Units (normalized)
14665.80	OO Units (normalized)
9.53	FH (normalized)

Table 10: Variable Inflations Factors

11 of the 14 variables were found to have an unacceptable VIF values; above 2. Therefore, the model was adjusted. After checking the VIF for many combinations of variables the following 2 analysis variable sets were chosen. The first is of 5 variables and it included the normalized household measures of owner occupied units, households with white alone population and households with female heads of households. The grouping also includes the median structure year built and the time

period dummy variable. The VIFs for this variable grouping is below:

VIF	Variables
1.044	Median Year Structure Built
1.020	Time Period
1.881	HHWA (normalized)
1.752	FH (normalized)
1.086	OO Units (normalized)

Table 11: Revised Variable Set #1 VIFs

The second grouping contained all the same variables, non-normalized, plus the addition of median household income. The normalized based on the total number of household units in the bus stop area to ensure there was not an unequal weighing occurring. The VIFs for this grouping are below:

VIF	Variables
1.058	Median Year Structure Built
1.011	Time Period
1.611	HH w/ White population alone
1.825	Owner Occupied Units
1.469	HH with Female Householder
1.950	Median Household Income

Table 12: Revised Variable Set #2 VIFs

These variables were all within an acceptable VIF threshold. The following regression models were utilized, using these new groupings, to test for the change from 2011 to 2016.

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	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	110.33	7.42	14.863	<0.000 ***
HHWA	0.07	0.01	10.533	<0.000 ***
Time Period	-18.76	2.58	-7.280	<0.000 ***
FH	-0.16	0.02	-7.349	<0.000 ***
Mean Year Built	-0.01	0.00	-3.341	<0.000 ***
HH Owner Occupied	-0.05	0.01	-4.084	<0.000 ***
Mean HH Income	0.00	0.00	0.549	0.583
HHWA x Time Period	0.00	0.01	0.581	0.561

Multiple R-squared: 0.192	
Adjusted R-squared: 0.1897	

Table 13: SERVICE AREA area = HH White Alone + Median income + Median Year Built + Female Householder + Time Period + HH Owner Occupied + HH White Alone x Time Period

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	107.49	7.32	14.693	< 0.000 ***
FH	-0.12	0.03	-4.527	< 0.000 ***
Time Period	-12.21	2.75	-4.435	< 0.000 ***
HH WA	0.08	0.01	14.445	< 0.000 ***
Mean Year Built	-0.01	0.00	-3.385	< 0.000 ***
HH OO	-0.04	0.01	-3.887	< 0.000 ***
Mean HH Income	0.00	0.00	0.445	0.656
FH x Time Period	-0.08	0.04	-2.292	0.022 *

Multiple R-squared: 0.1933	
Adjusted R-squared: 0.1906	

Table 14: SERVICE AREA area = HH White Alone + Median income + Median Year Built + Female Householder + Time Period + HH Owner Occupied + Female Householder x Time Period

These results show more significance variables but reaffirms the negative relationship between households with a female head of household and their level of access. The interaction between the Female head of household variable and the Time Period variables shows significance at the 0.01 level for the drop-in access from 2011 to 2016. The regression results utilizing the normalized variables are below:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	128.526	9.091	14.138	<0.000 ***
HH WA (normalized)	12.57	5.33	2.358	0.01849 *
Time Period	-19.25	3.96	-4.857	<0.000 ***
FH (normalized)	-118.87	13.71	-8.671	<0.000 ***
Mean Year Built	-0.01	0.00	-3.175	<0.000 ***
HH Owner Occupied	-0.01	0.01	-0.568	0.570
Mean HH Income	0.00	0.00	-1.834	0.067
HHWA (normalized) x Time Period	3.91	6.31	0.619	0.536

Multiple R-squared: 0.1633
Adjusted R-squared: 0.1605

Table 15: SERVICE AREA area = HH White Alone (normalized) + HH Owner Occupied (normalized) + Median income + Median Year Built + Female Householder (normalized) + Time Period + HH White Alone (normalized) x Time Period

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	129.33	8.63	14.979	< 0.000 ***
FH (normalized)	-72.62	17.24	-4.212	< 0.000 ***
Time Period	-12.26	3.33	-3.680	< 0.000 ***
HH WA (normalized)	20.54	4.21	4.880	< 0.000 ***
Mean Year Built	-0.01	0.00	-4.016	< 0.000 ***
HH OO (normalized)	-35.61	4.31	-8.258	< 0.000 ***
Mean HH Income	0.00	0.00	1.323	0.186
FH (normalized) x Time Period	-22.06	17.44	-1.265	0.206

Multiple R-squared: 0.1905
Adjusted R-squared: 0.1878

Table 16: SERVICE AREA area = HH White Alone (normalized) + HH Owner Occupied (normalized) + Median income + Median Year Built + Female Householder (normalized) + Time Period + Female Householder (normalized) x Time Period

When normalized the interaction is no longer significant. The negative relationship between the number of Female Householder households and the size of the areas of accessibility still is significant.

CONCLUSION

While the presence of significance is not consistent throughout all of the results there is a repeated finding of a negative relationship between the households with female head of households and access as measures by network analysis. This presents a prime case for future study. While not explicitly stated in the plans goals, there should be attention given to female lead households and making sure that they have access through the public transportation system. Further study should include a spatial exploration of these households across the city. Additionally the network frequency and performance should be included. More study is needed once distinct census data sets are available for a true study of the change from 2011 to 2016. Also, an additional consideration would be use the total population of a census tract as a weight for all variables in this regression. This is based in the idea that the system was designed to increase ridership and therefore population of a census tract or area should be considered in judging the improvements. All access increase is not the same. Another component of the service that could be added to the network analysis is a consideration of the frequency of service.

Over all, the study’s main finding is the change in access for households with female householders experienced a loss in area access between 2011 and 2016. This calls for additional exploration of the access that was provided and additional exploration of the Reimaging projects methods. The methodology for analysis, while sound, could be approved upon to be more useful.

REFERENCES

Adler, Moshe. 2010. “Economics for the rest of Us: debunking the science that makes life dismal” New Press: Distributed by Perseus Distribution New York; London

"Austin Plans a Bus Network Redesign of Its Own." Streetsblog USA. September 09, 2016. Accessed March 07, 2018. https://usa.streetsblog.org/2016/09/09/austin-plans-a-bus-network-redesign-of-its-own/.

Bullard, Robert Doyle, Glenn Steve Johnson, and Angel O. Torres, eds. 2004. “Highway robbery: Transportation racism & new routes to Equity”. South End Press.

Bullard, Robert. 2004. “Addressing Urban Transportation Equity in the United States”, 31 Fordham Ubr.L.J 1183, 1210

Currie, Graham. "Quantifying Spatial Gaps in Public Transport Supply Based on Social Needs." Egyptian Journal of Medical Human Genetics. May 02, 2009. Accessed May 07, 2018. https://www.sciencedirect.com/science/article/pii/S0966692308001518.

Factbook 2016 APTA. Accessed November 1, 2017. Source http://www.apta.com/resources/statistics/Documents/FactBook/2016-APTA-Fact-Book.pdf.

Garrett, Mark, and Brian Taylor. 1999. "Reconsidering social equity in public transit." Berkeley Planning Journal 13, no. 1.

Grengs, Joe. 2002. “Community-Based Planning as a Source of Political Change: The Transit Equity Movement of Los Angeles’ Bus Riders Union.” Journal of the American Planning Association 68 (2): 165–78

"Houston History: Timeline - Houston Visitors Bureau." Visit Houston. Accessed April 5, 2018. H ttps://www.visithoustontexas.com/about-houston/history/.

MacKechnie, Christopher. 2017. "How Much Does It Cost to Purchase and Operate a Bus?"

ThoughtCo. Accessed April 18, 2018. https://www.thoughtco.com/bus-cost-to-purchase-and-operate-2798845.

METROwebmaster@ridemetro.org. "GTFS." METRO Home. Accessed September 07, 2017. https://www.ridemetro.org/Pages/NewsDownloads.aspx.

Palmateer, Chelsey, Andrew Owen, David M. Levinson, and Alireza Ermagun. "The Role of Transit Service Area Definition in Accessibility-based Evaluation." (2016). https://conservancy.umn.edu/bitstream/handle/11299/181536/The%20Role%20of%20Transit%20Service%20Area%20Definition%20in%20Accessibility-based%20Evaluation.pdf?sequence=5

Pang, John Zhen Fu, Nasri Bin Othman, Keng Meng Ng, and Christopher Monterola. 2015. "Efficiency and Robustness of Different Bus Network Designs." International Journal of Modern Physics

Public Transportation Association, American, and Matthew Dickens. 2017. "APTA Q1 2017 Ridership Report."

Pritchard, Gavin John. 2015. "Frequent Network Bus Systems : An Analysis of Houston's Bus Re-Imagining's Impact on Access" APPROVED BY SUPERVISING COMMITTEE

"Reimagined 5-year Transit Service Plan. Report. METRO. 2014 Accessed September 10, 2017. http://t4america.org/2016/12/15/with-other-cities-trying-to-replicate-houstons-successful-bus-network-overhaul-marylands-plan-for-baltimore-falls-short/.

"System Reimaging Chapter 1 Existing Conditions". Report. METRO. 2014 Accessed September 10, 2017. https://www.ridemetro.org/MetroPDFs/AboutMETRO/CurrentProjects/pdfs/Reimagining/Existing-Conditions-Report.pdf

Tribby, Calvin P., and Paul A. Zandbergen. 2012. "High-Resolution Spatio-Temporal Modeling of Public Transit Accessibility." Applied Geography 34 (4): 345–55.

"Urban Population Growth (annual %)." GDP Growth (annual %) | Data. Accessed January 15, 2018.https://data.worldbank.org/indicator/SP.URB.GROW?end=2016&start=2016&view=map.

U.S. Census Bureau. 2018. LEHD Origin-Destination Employment Statistics Data (2002-2015) [computer file]. Washington, DC: U.S. Census Bureau, Longitudinal-Employer Household Dynamics Program [distributor], accessed on March 2017 at https://lehd.ces.census.gov/data/#lodes. LODES 7.3 [version]

"U.S. Census Bureau QuickFacts: Houston City, Texas." U.S.Accessed May 1, 2018. https://www.census.gov/quickfacts/fact/table/houstoncitytexas/PST045217#qf-headnote-b.

U.S. Census Bureau; American Community Survey, 2015 American Community Survey 5-Year Estimates, Table B01003; using American FactFinder; http://factfinder.census.gov; (27 Feb 2018).

-- B11001
-- B19013
-- B25035
-- B25003
-- B25003A

"While Other Cities Try to Replicate Houston's Successful Bus Network Overhaul, Maryland's Plan for Baltimore Falls Short." Transportation For America. January 27, 2017. Accessed May 01, 2018. http://t4america.org/2016/12/15/with-other-cities-trying-to-replicate-houstons-successful-bus-network-overhaul-marylands-plan-for-baltimore-falls-short/.