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Measuring Access to Employment to Guide and Evaluate Public Transit Service Planning in New Orleans

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Keywords: Transportation; Public Transportation; OpenTripPlanner

Table of Contents

Table of Figures

List of Tables

Abstract

New software and technology is making it easier than ever before for public transportation planners to evaluate how quickly residents can reach jobs and other destinations. Because in the past it was difficult to measure access to opportunities, these concepts remained primarily in the theoretical and academic realms of research. This thesis reviews methods that could be used to evaluate routine bus service improvements and performs a comparative analysis of different methods in the context of New Orleans. There are many different variables in how the analysis could be performed, but this thesis focuses on the role that time of day plays in analyzing service changes. The results show that accessibility can be a very useful metric to evaluate the effectiveness of transit service changes. It goes on to explore techniques that could assist transit planners and schedulers to identify service gaps and prioritize service changes.

1 Introduction

1.1 Background

It’s easy to answer the question of whether an individual has access to broadband internet, natural gas lines, the electrical grid, etc. and sometimes there is an inclination to regard access to public transportation in the same terms, perhaps by asking if there is a bus stop within a quarter of a mile. Utilities and public transportation are often both illustrated by drawing lines on a map, but we know that a particular transit stop may connect to transit line that comes frequently or infrequently, travels quickly or slowly, and goes to destinations that are close or far away. These variables and many others represent the mobility that is provided by public transportation service. Mobility refers to one's ability to move about freely and is often measured by speed, travel time, or distance (Hanson, 2004). Unlike utilities that provide a standard level of quality to everyone that’s connected, the mobility that is offered by access to transit can vary tremendously. When planners wish to evaluate the effectiveness and usefulness of public transportation, it is therefore reasonable that planners should not only measure the distance to a transit stop or even the mobility of the connecting transit line. Importantly, planners should also measure how transit provides access to destinations and opportunities.

Definitions of access have been viewed differently over the years and many academics have created their own definitions. “These include such well-known definitions as ‘other potential of opportunities for interaction’ (Hansen, 1959), or ‘the ease with which any land-use activity can be reached from a location using a particular transport system’ (Dalvi and Martin, 1976), ‘Other freedom of individuals to decide whether or not to participate in different activities’ (Burns, 1979) and ‘Other benefits provided by a transportation/land-use system’ (Ben-Akiva and Lerman, 1979)” (Geurs et al., 2004: 128).

Geurs et. al. (2004: 128) go on to form their own definition of accessibility, “Focusing on passenger transport, we define accessibility as the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s).”

Defining accessibility is growing in importance today because technological advances and improvements in data availability have made it much easier to perform accessibility analysis. As this capability moves into the hands of more planners and city officials, it will become increasingly important to understand the best ways to interpret the data appropriately. A great deal of the work being done in this field is in the theoretical or academic realm (Tomer et. al., 2016(b)), and it is often geared toward informing communities how their transit is working at a fixed point in time. This may be adequate for planning efforts related to land use and long-term infrastructure projects, but more research is needed to determine how accessibility metrics can be used to assist in planning and scheduling for transit agencies.

Politicians and community stakeholders have a strong desire to improve access, in particular access to employment. The mayor of New Orleans, Mitchell Landrieu, recently expressed that sentiment in his State of the City address. After discussing a variety of initiatives to create more employment opportunities in the city, Mayor Landrieu stated, “And getting people to and from these jobs is really important. That’s why we’ve announced a major expansion of public transit, with more overnight RTA service, more buses on the busiest routes, and a new airport line. Plus, this fall a new streetcar along Rampart Street and St. Claude Avenue will be done” (Landrieu, 2016, p. 6-7). Clearly, city officials in New Orleans see access to jobs as a key reason for investing in public transit and if the city is going to improve access, it will be important to define it appropriately.

1.2 Research Questions

This thesis examines different methodologies for measuring job access via public transportation and investigates how accessibility measures can be used to evaluate transit service changes in New Orleans. In particular transit service varies greatly over the course of the day and this thesis will explore how those variations can be included in analysis. The general goal of the thesis is to see how accessibility analysis can be used on a routine basis to inform decision makers at the higher levels of government and also by transit planning and scheduling staff to perform a more detailed analysis. Specifically, this thesis investigates three questions:

1. Can a simple accessibility metric be used to evaluate transit service changes?

One potential function of an accessibility metric would be to provide a simple way to demonstrate the impact of transit service changes to policymakers. For example if the RTA board is evaluating a service change that has been brought forward by the planning department, it would be beneficial for them to have a single figure that could be used to evaluate the effectiveness of the service change. For this question, it will be essential to evaluate different summary metrics for job access in the city. Different organizations have recently advanced such metrics and they will be discussed in more detail in section 2.3. This question asks if there is a consolidated metric that goes beyond what has been provided in the past to offer a comprehensive evaluation of service improvements over 24 hours in a single number.

2. How can accessibility analysis be used to assist in developing schedules during routine transit service changes?

This question asks how planners and transit agency staff members can use accessibility metrics as part of the iterative process of developing transit schedules. The analysis performed for this project generated a large amount of data and while the first question aims to distill it down to single figure, this question will require a deeper dive into the data output. Transit schedules are developed and modified constantly over time to respond to changing needs of the community and require a detailed consideration of how the different transit lines interact and support one another. These network effects are seamlessly included in accessibility metrics, and it therefore seems possible that they may offer insight into the planning process.

3. Can accessibility analysis be used to measure progress towards the goals of public transit in a community?

The goals of a transit agency are not always straightforward or even clearly defined by the organization so measuring progress can be very complicated. Some agencies only want to reach the highest levels of ridership possible for their community to reduce congestion and emissions. Other agencies may consider a basic level of service to lower income communities as a higher priority than ridership alone. In spring of 2016 the RTA implemented a service change that increased their revenue hours by 11%, and grew the cost of operations by $4 million (Rainey, 2016). This final research question aims to see if accessibility metrics can be used to determine what goals are being targeted by this service increase.

1.3 Summary

This project begins with a review of research and planning projects that have been used to develop the basic concepts used in measuring access to destinations on public transportation. The review explains that the three basic components of accessibility measures are temporal, land use, and transportation and then describes the role of all three components in accessibility analyses. This is followed by a discussion of methods for quantifying access that range from the very intuitive cumulative opportunity metrics to the more sophisticated, but perhaps less transparent gravity- and utility-based metrics. The thesis also provides an overview some of the different ways that accessibility analysis is being applied in the planning realm, beginning with a review of the methodologies that were used to develop three of the leading resources for accessibility data. Finally there is a review of planning projects that have used accessibility metrics and notes the absence of accessibility metrics in the field of transit service planning and scheduling.

The third chapter is a detailed description of the methodology used in this thesis to evaluate how the time of day influences accessibility metrics. Performing this analysis required using millions of travel times in hundreds of origin-destination matrices, and for this reason, it is necessary to provide a detailed methodology to explain how the matrices were developed and analyzed.

The final chapter of the thesis offers a review of the data that was analyzed in this research and answers the research questions of this thesis. The analysis acknowledges that a single metric cannot capture all of the different dynamics at play in a service changes, but it may be the best way to simply summarize the impact of a service change proposal. Secondly, the analysis reveals that accessibility metrics can enhance the scheduling process by identifying where and when gaps in transit service occur. A key conclusion of the thesis is that there needs to be a larger body of research on this subject. This would make it possible to determine the correlation between the levels of accessibility to jobs provided by a transit network and actual ridership on the transit system.

2 Accessibility in Public Transportation

2.1 Components of Accessibility

Accessibility is most commonly described as an analysis of the two-dimensional relationship between land use and transportation, but any realistic analysis should additionally include consideration of components described by Geurs and Van Wee as “temporal” and “individual” (Geurs, 2004: 128). Transportation represents mobility and the freedom of an individual to reach other places. Land use represents the destinations and opportunities that an individual may seek to access. Land use is composed of all of the physical destinations that exist in the world and commonly include workplaces, shopping, healthcare facilities, and recreation.

2.1.1 Land Use

For many people, the trip to work is the most important trip of the day. Additionally, they are often people’s longest trip of the day and they tend to happen during peak travel periods when transportation systems are used most intensely. For this reason, access to jobs is sometimes the only access measure that is evaluated by transportation planners. Planners are the most concerned with the capacity of transportation infrastructure during the times when it is under the greatest demand.

The US Census Bureau provides excellent data on job locations that allow for detailed analysis that considers the location and type of jobs in any community. This is important because not all jobs and workers are compatible. For example, a suburban neighborhood with predominantly highly educated residents may not find utility in the nearby low-wage retail job opportunities. The data provided by the Census’s Longitudinal Employer-Household Dynamics (LEHD) program shows how many jobs are on every block and the industry, wage, and educational requirements of the job (Ramsey, et al, 2014). This allows analysis to be tailored to consider the utility of job opportunities for a particular population. The same data can be used to evaluate the inverse of job access by determining the number of workforce members who can reach a particular destination.

The range of destinations that could form the basis of an accessibility analysis is literally limitless. Most commonly this analysis is done to evaluate access to jobs because this is a destination that has very clear economic implications and the morning and evening commutes to work put the most strain on a community's transportation system. However, many policy makers and urban planners have a desire to measure to access retail, healthcare, educational, social and recreational facilities among others by all different modes of transportation. Section 2.4 offers an example of a housing study in Alabama that measured access to schools, healthcare facilities, community centers, schools, and more to evaluate the best locations to make investments in affordable housing.

One of the difficulties in creating accessibility metrics is that origins and destinations are points and most accessibility metrics relate to the ability of individuals in a particular area to reach other destinations. I.e. An accessibility analysis will often aim to assign the access traits of a particular point on the map to a more general area on the map. The analyst must therefore make a determination on the appropriate geographical area to associate with the access information gathered for a specific point. It is possible to create a geographical area based on a grid or some other geometry, but more commonly the analyst will choose a geography that already exists and has demographic and other descriptive data associated with it (metadata), such as a census block group (CBG) (GitHub, 2016). The advantage of using geographies with metadata is that they allow the analyst to appropriately weight trip origins when aggregating the data for a larger study area (see section **Error! Reference source not found.**) and identify the opportunities that are present at the destination. The advantage of creating a geography from scratch is that it allows the researcher to ensure that when many trip origins are being evaluated, they cover a study area evenly and offer the specific resolution that a researcher desires. The trip origin for the geography is based on either the geometric centroid or some sort of weighted centroid. A weighted centroid will often be based on the distribution of population or job opportunities within the geography. This can be particularly useful when a geography borders a large body of water or uninhabited space that move the geometric centroid into an area that is not accessible by the street grid.

As previously discussed, accessibility at its most basic applies to a particular point of origin, but must sometimes be generalized to the geography. It is also frequently necessary to aggregate the data collected for many origins and their associated geography. A common way to do this is to create a weighted average wherein the number of jobs accessible from each CBG is weighted by the percentage of workers residing in that CBG. The result is a single metric that represents the accessibility value experienced by an average worker in the analysis' study area (Owen, 2014).

2.1.2 Transportation

The transportation component of accessibility could be defined as the disutility of travel between a particular origin and destination for an individual. Disutility simply refers to any impediment that an individual may encounter in their trip. This is most commonly considered time, but it could also be considered financial expense, risk of an accident, personal comfort, and many more things. (Geurs et al., 2004)

A transportation network is a system of thoroughfares and transportation modes that can be used to make trips from an origin to a destination. Transportation network data are composed of lines that include varying levels of data that may relate to capacity, speed limits, mode availability, and public transportation. Some corridors such as interstate highways may be unavailable to pedestrians and cyclists while greenways maybe exclude private motorized vehicles. Those characteristics are typically included in the metadata for road network data provided by the census bureau or OpenStreetMaps (OpenStreetMap.org, 2016).

Alternatively, transit network data are usually available independently of road network data through transit routes and schedules. Google assisted in developing a standard digital format for this data called General Transit Feed Specification (GTFS) in collaboration with TriMet, the transit agency in Portland, OR. Google defines GTFS as “a common format for public transportation schedules and associated geographic information. GTFS ‘feeds’ let public transit agencies publish their transit data and developers write applications that consume that data in an interoperable way ” (Google Developers, 2016(a)). The GTFS can be joined with road network data to plan trips based on a transit agency’s actual route and schedule data.

Accessibility metrics depend on sophisticated analysis of spatial data and large datasets. Some researchers use transportation network data to determine what areas can be accessed, while others make assumptions about certain components in a trip to create a synthesized travel time. One of the most common assumptions is that a simple radius around a trip origin will define an access threshold. For example some studies will assume that pedestrians will use a transit stop that is within a ¼ mile of their residence because it is a 5-minute walk away. However, a geodesic radius of ¼ mile may include many destinations that would require a traveler to walk more than a ¼ mile using the road network (See Figure 1). The Center for Neighborhood Technology and the EPA performed their accessibility analysis with synthesized travel times and they are discussed in more detail in section 2.3.

2.1.3 Temporal

The temporal component of access is the primary focus of this thesis and it refers to constraints on the availability of opportunities attributable to time of day and the time requirements of a particular activity (Geurs, 2004). It is possible for an individual to reach any destination eventually so for that reason most accessibility metrics include a time threshold during which a trip must be achievable. Additionally, the point in time will have an influence on the ability of individuals to travel and the number of opportunities that the individual may wish to access. Section 2.2.2 discusses how gravity-based models might evaluate trips at various thresholds and weight trips differently based on the length of the trip or time of day. In the context of employment, the temporal component relates to the duration of an individual's commute and the time of day during which the commute must be completed.

Traffic and congestion levels vary greatly during the course of the day and as a result travel times tend to be longer during the peak travel periods. In New Orleans for example, trips take 32% longer during peak hours compared to off-peak hours (Schrank 2015). Congestion is very difficult to measure because it varies based on the day, time of day, and individual road segment. A variety of new data sources have come about recently to assist with calculating congestion as a result of the availability of data collected on GPS-enabled mobile devices onboard vehicles (Kim, 2014). One publicly accessible resource to provide vehicular travel delay information is through the Google Directions API, which allows analysts to perform queries that provide a travel time estimate, based on real-time or average traffic conditions for a specific time and day. However, the API and pricing schedule are designed for developers that are creating apps that allow people to request directions so it would be very expensive to perform an analysis that required performing millions of queries (Google Developers, 2016(b)).

Levels of transit service vary tremendously throughout the course of the day and week. Some agencies do not offer service on Sunday or late at night. Furthermore, infrequent service might mean that levels of access vary throughout the course of the day. One technique for compensating for this variance throughout the course of the day is to record multiple observations of travel time at regular intervals over the course of the day and then average them. (Owen, 2014)

Different jobs require workers to arrive at their place of employment at different times of day. This can present challenges if the mobility provided through the transportation network varies though the course of the day. For example, a transit line may provide access to an individual's place of employment between 6 a.m. and 9 p.m., but it is not useful to the individual if their shift begins outside of that timeframe. A strategy to roughly approximate these effects is to calculate travel times during multiple times of day and weight each observation by the percentage of commuters that normally leave for work during that period (Legrain, 2015). This technique offers an untraditional version of a gravity-based metric in the sense that the “gravity” usually relates to travel time rather than time of day (Stewart, 2014). Legrain (2015) used this technique to determine whether using peak travel periods alone was sufficient to measure the levels of access available from different parts of Toronto and the research concluded that only using the peak period is sufficient to identify which parts of Toronto had poor access and good access to jobs on transit.

2.1.4 Individual

The individual component of accessibility refers to the variation in specific needs, wants, and destinations of individuals. Some individuals may be unable to walk to a nearby bus stop because of mobility impairments and that would clearly have great impact on their personal mobility (Geurs, 2004). Furthermore, an individual may have access to many jobs nearby, but none of them may offer the optimum opportunity for employment. This condition has be studied extensively and relates to the spatial mismatch hypothesis which refers to the fact that many low wage jobs have moved out of the urban core while low-wage housing has not (Kain, 1968). Legrain (2014) documented evidence in Toronto that low-income individuals commute to work at different times of day than high-income residents.

2.2 Methods for quantifying access

2.2.1 Cumulative Opportunity Metrics

Cumulative opportunity measures of accessibility are based on a relatively simple function of how many opportunities are accessible within a given threshold that is most commonly based on time, but could be based on any number of variables including distance, financial cost, or carbon emissions. Visual representations of the areas accessible through the cumulative opportunity metric are referred to as isochrones (Geurs et al., 2004). Figure 1 offers an example of isochrones depicting a 30-minute access shed in New Orleans from a particular trip origin. Based on what was previously discussed in section 2.1.3, it is easy to imagine how the shape and size of the isochrones would vary based on the time of day and travel time threshold. It is also notable that in Figure 1 Mapnificent uses an assumption that once an individual arrives at a transit stop, they are not restricted in their movement by the street grid. For example parts of Lake Pontchartrain appear accessible even though there are definitely no pedestrian facilities and it is unlikely to be frozen solid enough for pedestrians to safely travel across it. This thesis is based on the cumulative opportunity metric and uses attribute data from OpenStreetMap to determine which roadway components are accessible to pedestrians.

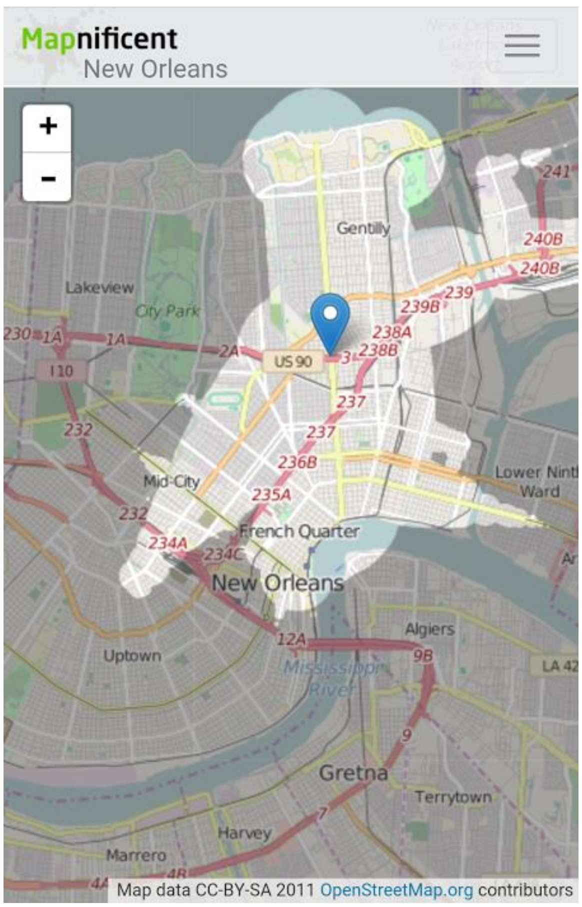


Figure 1: Example of isochrones for cumulative opportunities metric
Source: Mapnificent.net, Retrieved: July 21, 2016; Map data: CC-BY-SA OpenStreetMap.org contributors

2.2.2 Gravity-based Metrics

Gravity-based metrics are an extension of the cumulative opportunity metric that allows for different opportunities to be weighted differently. It is common to weight opportunities based on how easily they can be accessed from a particular trip origin. Ease of access in this case could be measured by distance, cost, or travel time. Stewart (2014, p. 26) offers an example of an impedance function in which:

> the number of opportunities at a given destination could be multiplied by 100 over the square of the time it takes to travel there from the selected origin. If this impedance function is used, and if in [Figure 2], the travel time from A to X is 10 minutes, from A to Y is 20 minutes, and from A to Z is 31 minutes, then the total accessibility score for A will be:
>
> $A_A = 100/10^2(2) + 100/20^2(10) + 100/31^2(5) = 5.02$

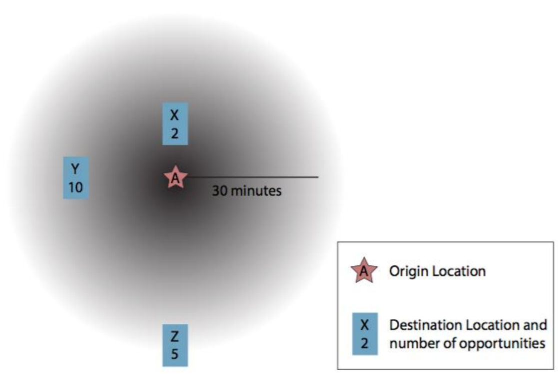


Figure 2: Gravity metric example
Source: Stewart, 2014, p. 26.

This example illustrates the way that in a gravity-based metric it is possible to eliminate a rigid threshold in favor of an impedance function or some other weighting schedule that allows analysts to remove hard and fast limits from their analysis. In the example offered above the closest thing to a threshold is that as the travel times increase, the value of jobs will eventually reach a level that is so low that they round down to zero. The challenge in this technique is determining an appropriate way to weight opportunities based on behavioral data that can directly linked to access. As discussed in section

2.1.3, it is often necessary to calculate travel times at many times of day in an accessibility analysis; gravity models can also be used to give more weight to trips that are performed at a particular time of day (Legrain, 2015).

2.2.3 Utility-based Metrics

Utility-based metrics primarily revolve around the conditions experienced by an individual and reflect the opportunities that they seek to access. Performing this sort of analysis requires assessing the relative value of different destinations on an individual basis and is difficult to apply on a generalized basis due to lack of data and resources (Geurs, 2004).

2.2.4 Comparing Metrics

Cumulative opportunity metrics are the factors that are most commonly used in accessibility metrics because it is often difficult to understand the various weights and equations that can potentially go into gravity-based metrics. Most planners would agree that it is important to use multiple metrics when accessibility on a transit network is being evaluated, but if it is only possible to use one metric, it would probably be essential that it be a gravity-based metric so that it’s possible to take into consideration a wide variety of information and avoid thresholds which may misrepresent levels of access in certain cases.

2.3 Resources for Accessibility Data

Many different resources have been developed over the past several years to make accessibility data available to the public and there is a substantial difference between the methods that they use to calculate levels of access. This thesis is primarily focused on understanding how temporal variables can influence the results of accessibility analysis and how accessibility can be used to evaluate transit service changes. The three examples offered in this section use different methodologies to measure access to jobs and this review is to identify a possible methodology to evaluate transit service changes in New

Orleans. A key difference between the methodologies is that the EPA Smart Location Database and the Center for Neighborhood Technology's AllTransit tool synthesize certain portions of the trip in their travel time calculations while the Accessibility Observatory at the University of Minnesota (UMAO) uses routing software to determine travel times.

2.3.1 EPA Smart Location Database

The EPA's Office of Sustainable Communities has conducted research that indicates that more compact, walkable communities can lead to better public health and environmental outcomes (Kramer, 2014). In response to these findings, the EPA has developed the smart location database to provide communities with a tool to compare the locational efficiency of neighborhoods across a MSA and the United States. The dataset includes an online portal and downloadable GIS files that allow users to select variables related to the accessibility that the EPA authors performed. It is therefore possible for planners to use these data to inform decisions regarding transportation and investments into housing. One particular focus of the dataset is on work force accessibility, which will help stakeholders to determine how many high- and low-wage earning members of the community's workforce are within a 45-minute trip on transit to a particular location. This information will allow decision makers to know whether large new employment centers will in fact improve job access in their community without requiring them to relocate (Ramsey, et al, 2014).

The EPA chose a methodology for determining access that could be described as artificial or synthesized and is not in fact based on specific travel times. The strategy that the researchers pursued required the calculation of travel times in several stages into different matrices and then synthesizing them into a single travel time between CBGs. First they calculate walk times from every CBG centroid to every transit stop within a 15-minute walk. They then calculated the optimum travel time between every transit stop between 5:00 PM and 5:45 PM, allowing for up to ten minutes to transfer, including up to five minutes to walk to the transfer location. The final step to calculate the total travel time between CBG centroids is to measure the travel time from the destination transit stop to CBG centroids within a 15-minute walk. The analysts acknowledged that some trips could be made more quickly on foot alone than using the transit system and made allowances for such cases in their calculation of travel time. Walk-times are calculated using road network data from, NAVTEQ NAVSTREETS which includes attribute information indicating which thoroughfares offer pedestrian access. Transit vehicle travel times are determined based on GTFS data from transit agencies that make this data available. The EPA performed the data analysis for every community in the United States that has made their GTFS public and Figure 3 provides a screen shot illustrating how that enables users to easily compare access in different cities. Such agencies account for 88% of transit ridership in the country (Ramsey, et al, 2014).

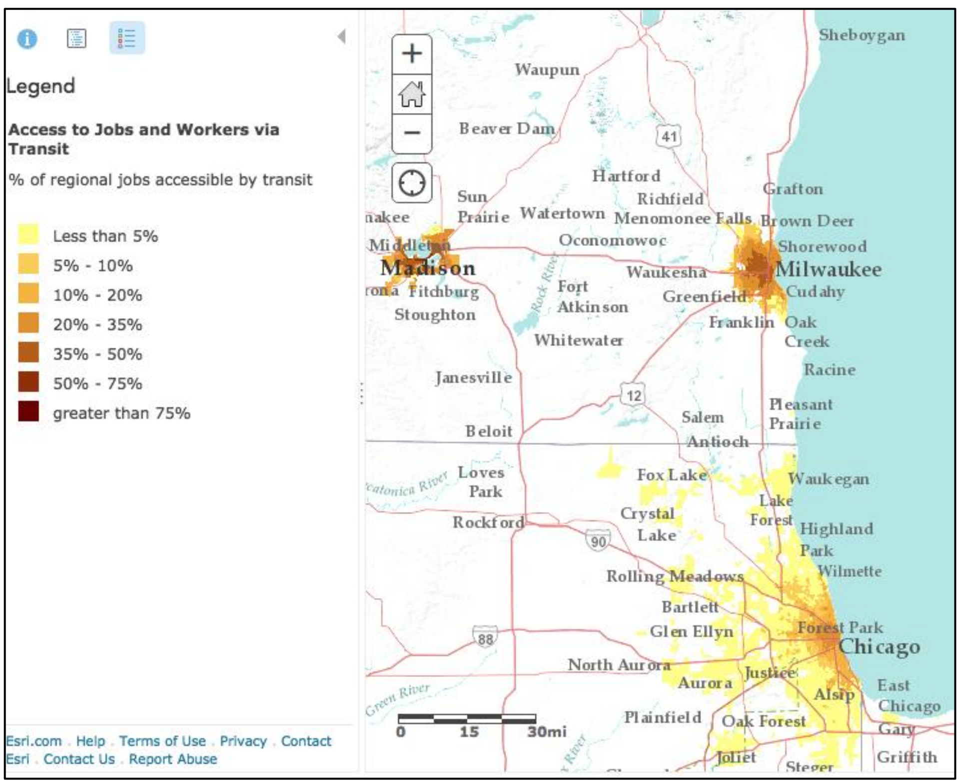


Figure 3: Smart Location Database Transit Tool
Source: epa.gov, Retrieved: July 21, 2016. Map Data: Esri, USGS, NOAA, DeLorme, NPS

2.3.2 University of Minnesota Accessibility Observatory

The Accessibility Observatory (UMAO) at the University of Minnesota is a program of the Center for Transportation Studies and the Department of Civil, Environmental, and Geo- Engineering that is focused on providing accessibility data to enhance communities' ability to plan and evaluate transportation systems and land use in their areas. UMAO's Access Across America report provided a methodology for comparing accessibility by transit between cities and has applied their techniques to perform studies to compare access before and after transit enhancements and perform customized research and analysis for government organizations. Their Access Across America report provides data downloads, analysis, and maps regarding job access in 46 of the 50 most populous MSA's in the US (Owen, 2014).

UMAO's methodology for calculating access is striking in its simplicity, robustness, and level of detail. Instead of calculating the travel times between CBGs, they draw from US Census Bureau's Longitudinal Household-Employer Dynamic (LEHD) Origin-Destination Employment Statistics (LODES) dataset to measure the travel time to jobs for every census block in the metro area. Additionally the analysts include all census blocks within 60 kilometers of the MSA to ensure that the full travel radius of residents in the area is given appropriate value even if it is far outside the MSA. They perform observations of travel time every minute and then average the number of jobs accessible at every interval between 7:00 AM and 9:00 AM. The data is available as the number of jobs accessible in travel time thresholds of 10, 20, 30, 40, 50, and 60 minutes and they also provide a gravity-based metric that provides a weighted average across those thresholds based on a formula that more heavily values jobs that are closer to the origin. This large, detailed geography and frequency of travel time observations means that altogether the researchers may have to analyze upwards of one trillion trips to form their calculations. The road network data comes from OpenStreetMap and agency GTFS files. Figure 4 shows their map of the data for the New Orleans MSA and is notable for the high resolution in their results.

(Owen, 2014). The methodology used in this thesis is largely modeled off of the one used by UMAO, but due to lack of computing power, the analysis was not performed at such a detailed and expansive level

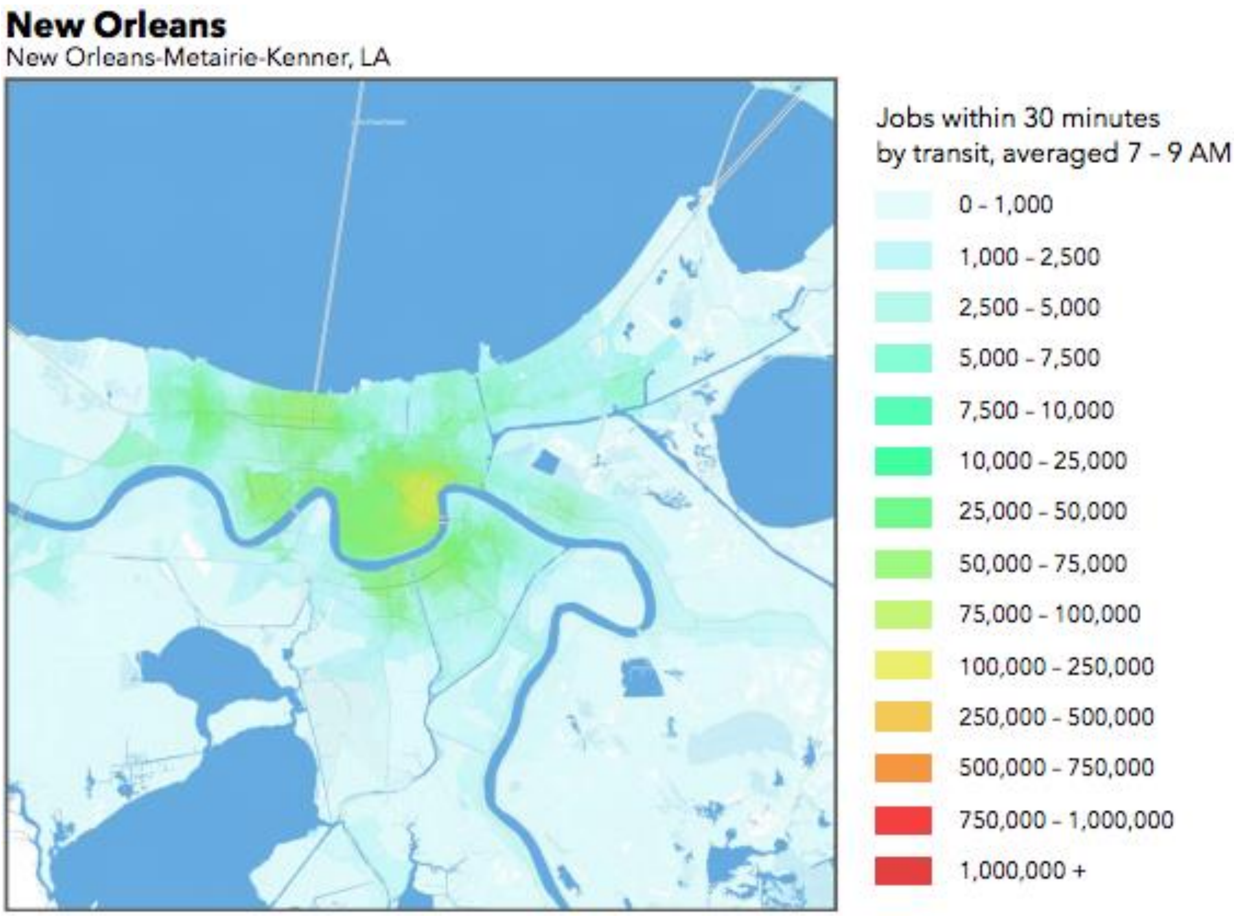


Figure 4: University of Minnesota Accessibility Observatory's Access Across America
Source: Owen, 2014, Page 61

2.3.3 Center for Neighborhood Technology AllTransit

The Center for Neighborhood Technology (CNT) is a Chicago-based research and advocacy organization whose goal is to improve urban economies and environments (CNT.org, 2015). In this work they maintains an interactive dataset that provides a vast array of details about public transportation systems in many communities across the United States. Included in the details that they provide is an estimate of how many jobs are accessible to the average resident within 30 minutes. The strategy that they use to calculate jobs that are accessible is based on first creating a “transit shed” for every CBG, which is the area that is accessible within 30 minutes and then calculating how many jobs are accessible within that area. The transit shed is composed of ¼ mile buffers around every transit stop that is accessible within 30 minutes on transit. The travel time between stops is based on the fastest trip of the day. They also assume that it is possible to make transfers between routes that serve stops within a quarter mile of each other within in 10 minutes. (CNT, 2016)

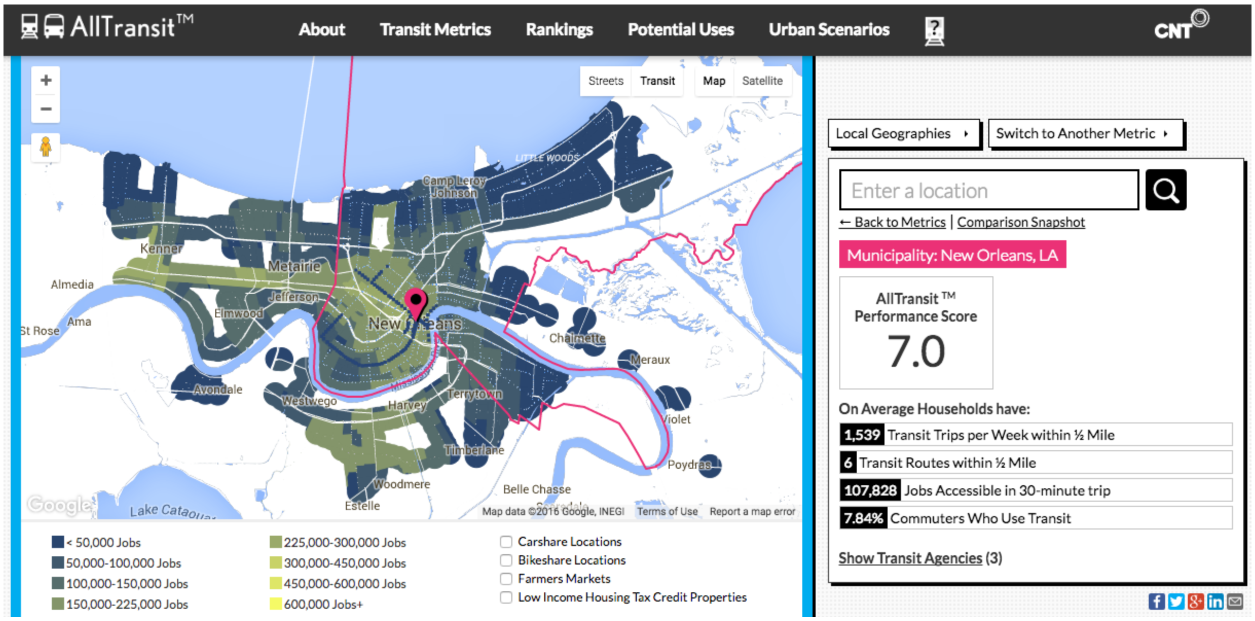


Figure 5: Center for Neighborhood Technology's AllTransit
Source: alltransit.cnt.org, Retrieved: July 21, 2016. Map Data: 2016 Google, INEGI

2.3.4 Comparison

Each of the tools presented in this section was designed to serve the goals of the particular organization. The greatest strength of the AllTransit tool is the comprehensiveness of the database that includes many agencies that do not publish their GTFS information and they include a broad number of maps and information about the service that goes beyond access. This allows the AllTransit tool to serve as a sort of benchmarking tool that lets any city compare their transit service with peer cities based on an objective scoring system. The weakness is that the job access component is not influenced by a route's frequency and the transit shed includes a simple buffer around transit stops rather than routing people on the pedestrian network. An interesting part of their methodology is that they have greatly limited the amount of walking that can be included in a trip to only about 5 minutes at three miles per hour from any origin or destination. Presumably the result of this is that the access metric focuses more on the transit component of a journey than on the walking.

The smart location database also uses a synthesized travel time for their transit travel time estimates, but the project is less oriented to public transportation than the other data resources. The EPA's goal of the project is more clearly to provide policy makers with information regarding where the most convenient locations are in their community as opposed to providing measure of the transit agency's performance. The database does this by providing widely applicable metrics for walkability and transportation costs that the other data resources do not have.

The UMAO data is interesting because it is very much oriented toward developing a process to compare access in the 50 largest MSAs and as a result is it very much oriented toward distilling an incredible amount of data into a single figure that will determine a MSA's ranking. This is problematic because it makes it difficult for transit agencies to use their data for analysis concerning specific issues such as prioritizing and evaluating service changes. However, their methodology is quite robust and the principals they use can serve as a guide for other analysis with goals other than developing a ranking. UMAO is also different from the other data resources in that it uses OpenTripPlanner to select a trip route based on actual road and transit network data at different times of day. Both of the other metrics create a sort of synthesis of a transit trip out of different components and then create a very complex methodology for how to assemble those different parts. UMAO is very specifically focused on providing access data while both of the other resources aim to provide a broad spectrum of information about public transportation in communities. The EPA portal even provides specialized metrics that rate walkability independent of public transportation.

There are more resources for accessibility data in cities from the Brookings Institution and others, but they are all oriented toward comparing access between cities and providing general guidance on the most accessible parts of a city. However, UMAO uses a methodology that is versatile and similar techniques have been used in other planning studies to evaluate access to jobs and transit infrastructure investments. This thesis will explore whether this methodology can also be used to evaluate and inform routine transit service planning.

2.4 Accessibility in Planning

It has only recently become possible to easily measure access on public transportation networks and as a result there is not an extensive record of its use in public transit service planning. Indeed a discussion of accessibility in planning often relates to its absence from planning, particularly with regard to transit service planning. In August 2016, the Brookings Institution launched an initiative called Moving to Access (MTA) to "inform and promote a more socially focused, access-first approach to urban transportation policy, planning, investment, and services." (Tomer, et al. 2016(b)) When asked for examples of which cities and communities are effectively using accessibility in their planning work, Adie Tomer of the Brookings institute responded regarding the MTA initiative, "One of the premises for almost the entire project really is this idea of moving from theory into practice… It's almost hard to explain [*the topic of accessibility measures*] because it's been so theoretical so far and part of the problem is that there hasn't been a lot of practical application of these ideas yet" (Tomer et al. 2016(a): 21:00). This section will discuss some of the practical applications of accessibility in general land use planning and also transit service planning.

2.4.1 Accessibility in Land-Use Planning

The US Department of Housing and Urban Development (HUD) strongly emphasizes the importance of providing housing that offers residents access to opportunity (24 CFR Parts 5, 91, 92, et al.) and as a result many cities have begun to prioritize access in the their housing plans. In 2014, the City of Birmingham published the City of Birmingham Housing and Neighborhood Study that performed analysis that would guide future affordable housing investments in the community (City of Birmingham, 2014). As part of the planning effort, a website was developed (BirminghamHousingStudy.com) that illustrates the different demographic traits of Birmingham's neighborhoods and additionally provides detailed information regarding the number and type of jobs, schools, healthcare facilities and other destinations are accessible from each neighborhood. Figure 6 shows as an example that 2,204 construction jobs are accessible within 30 minutes on transit and walking from the Forest Park neighborhood. This data portal could improve decision-making for many developments in the City of Birmingham. Housing developers and employers could make more informed decisions based on what locations have the best access to jobs and workforce members respectively. Where previously the city may have been able to quickly identify how many parks or schools are in each neighborhood, they can now more specifically identify how many parks and schools are reachable from each neighborhood.

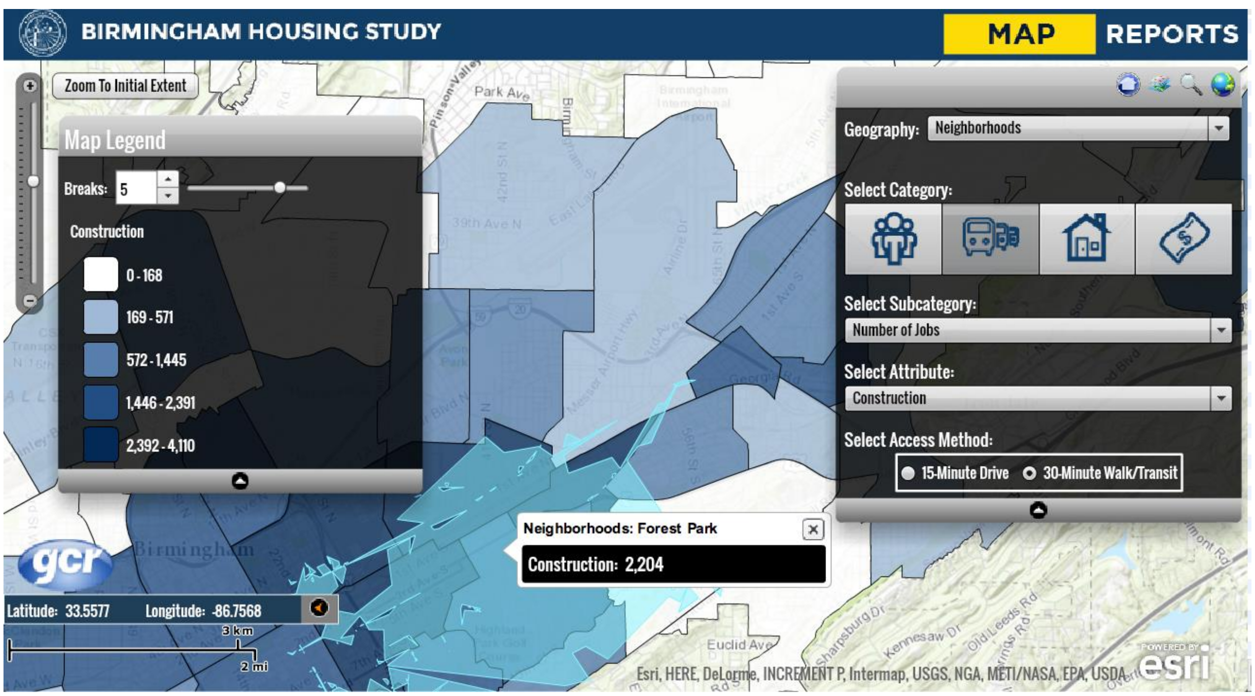


Figure 6: Screenshot from birminghamhousingstudy.com shows the number of construction jobs in accessible in 30 minutes.
Source: BirminghamHousingStudy.com, retrieved September 11, 2016. Map Data: Esri, HERE, DeLorme, INCREMENT P, Intermap, USGS, NGA, METI/NASA, EPA, USDA, GCR Inc.

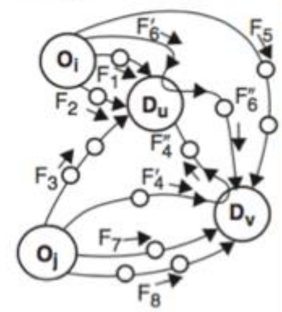
The World Bank has been a great innovator in connecting the planning practice and transportation investments with accessibility measures, performing accessibility analyses in a range of cities, including Cairo, Egypt; Lima, Peru; Mexico City; and Buenos Aires, Argentina (Quiros, 2015; Quiros, et. al. 2015; Eros, et al., 2014; World Bank, 2015). In Buenos Aires their analysis was oriented toward assessing the relationship between new development on the outskirts of the city and job access using public transportation. This analysis led them to conclude, “social housing is not being efficiently located in areas that offer its transit-dependent residents high employment accessibility” (Quiros, et al., 2015, p. 14). The authors also suggest that future analysis could determine whether high quality transit options in the periphery of the city will lead to more dense, location efficient development or if other policy measure could be required.

2.4.2 Accessibility in Transit Service Planning

There are a handful of different manuals for transit service planning that form a basis for the standard practice of service planning. In this research, some of the most commonly cited and referenced manuals for service planning were reviewed to see what role accessibility played in the service planning process. Here are the manuals listed:

- Mistretta, M., J. A. Goodwill, R. Gregg, and C. DeAnnuntis. Best Practices in Transit Service Planning, National Center for Transit Research, University of South Florida, Tampa, 2009.
- Ceder, A., 2007. Public Transit Planning and Operation: Theory, Modeling and Practice. Elsevier, Butterworth-Heinemann, Oxford, UK.
- Rainville Jr, W. S. *Bus Scheduling Manual. Traffic Checking And Schedule Preparation*. No. DOT-I-82-23. 1982.
- Pine, R., J. Niemeyer, and R. Chisholm. "TCRP Report 30, Transit Scheduling: Basic and Advanced Manuals." *TRB National Research Council* (1998): 18-21.

These manuals focus on the nuts and bolts of scheduling that include procedures like blocking, runcutting, and rostering, but they also include a wide range of metrics that can be used to evaluate route performance and assist with route scheduling and planning. *TCRP Report 30* and the *Bus Scheduling Manual* from DOT are based primarily on maximizing mobility and cost efficiency on bus routes and focus on scheduling buses rather than on the structure of routes in a community. The other two manuals by Misretta, et al. and Ceder provided more information on how agencies use the service area characteristics to design routes and develop service standards. The practices described in these manuals provide the core of transit service planning and are based on principals that have been in use for over 60 years (Ceder, 2007). The authors describe sophisticated methods to measure the performance and efficiency of bus routes and discuss the nuances associated with balancing competing interests in transit service planning. Ceder (2007) comes close to specifically identifying the value of accessibility measures in his discussion of "connectivity," but otherwise there is no evidence that accessibility metrics have found their way into common transit service planning and scheduling practices in the United States. Figure 7 offers a detailed explanation of Ceder's (2007) most complex definition of connectivity, which also most closely resembles a measure of accessibility. The measure that he presents is interesting because the weight of destinations is based on the actual number of transit trips that a location generates rather than some sort of metadata (e.g. number of jobs, type of retail, healthcare services available, etc.) that could be associated with a location. But the most important distinction is that when Ceder (2007) refers to connectivity measure components, he is referring to an impossibly complex range of variables that include average walking time to a transit stop, average waiting time, variance of waiting time, and variance of travel time. This is an impossibly complex range of variables for any sort of quantitative or algorithmic approach to service design and instead the formula is intended to illustrate the principles that should guide a more heuristic technique of balancing the different concerns presented in the formula.

Connectivity measure	Interpretation	Significance	Graphical example	Application
$C_D^F = \sum_{D_k \in D} C_{Dk}^{jF}, j = t, \ell$	Sum of all connectivity-component measures along all access paths to a set of destinations, weighted by the average amount of passengers using these paths	Overall exposure-connectivity measure for all paths in a given set of destinations		Evaluation of a set of destinations, considering exiting and new paths. ***Purpose***: comparison among airport destinations in a given set (e.g. zone-based, purpose-based)

Notations

For a given time window (e.g. peak-hour, average week-day):

$O = \{O_i\}$ = set of origins O_i
$D = \{D_u\}$ = set of destinations D_u
$P_{Dk} = \{P\}$ = set of inter-route and inter-modal paths to D_k
$P_{Ok} = \{P_i\}$ = set of inter-route and inter-modal paths from O_k
$M_p = \{m\}$ = set of transit routes and modes included in path p
t = index of quantitative attributes
ℓ = index of qualitative attributes
$E_t = \{e^t\}$ = set of quantitative attributes suitable for connectivity measures
$E_\ell = \{e^\ell\}$ = set of qualitative attributes suitable for connectivity measures
e^j_{mp} = the value of attribute e^j, $j = t, \ell$, related to mode m on path p
α_e = weight/coefficient for each attribute e^j, $j = t, \ell$
c^j_p = quantitative and qualitative ($j = t, \ell$) connectivity measure of path p
F_p = average number of passengers using path p
$c_p(i, j)$ = capacity (flow of passengers) of arc (i, j) between route and mode i, and between route and mode j; each i can also be an origin O_i or destination D_i; (i, j) is contained in path p and is part of a network-flow model.

Figure 7: Ceder offers a number of ways to measure connectivity. This example closely resembles some elements of general accessibility.
Source: Ceder, 2007, p. 392

The World Bank has begun to use accessibility measures to determine the propriety of investments into transit infrastructure and such a measure played a large role in their appraisal of a metro rail project that they are partially funding in Lima, Peru. Accessibility, measured by the increase in the number of jobs accessible in 60 minutes, was one of the five “Project Development Objective Indicators” that will be used to evaluate the successfulness of the project and played a part in determining the feasibility of the project.

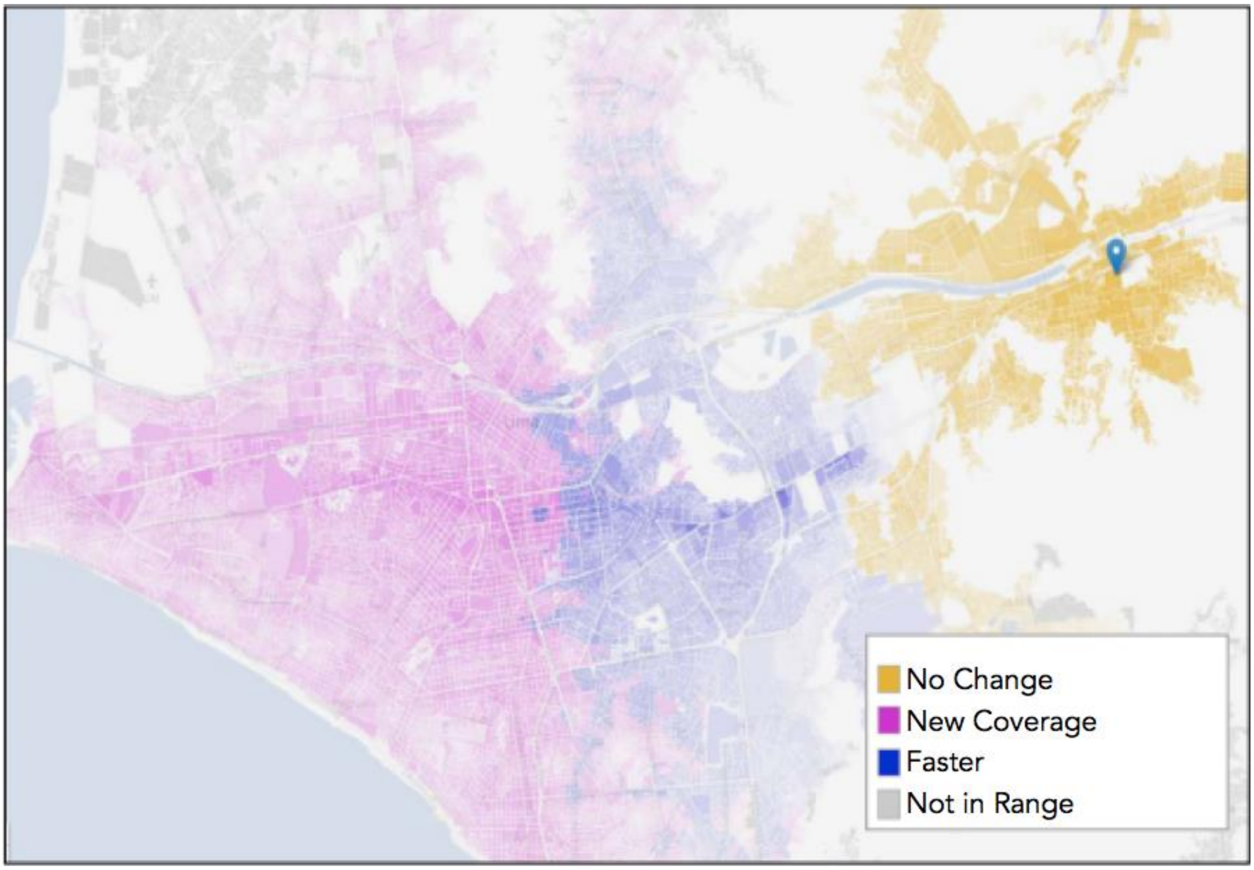


Figure 8 shows a key component of the analysis that they performed; the yellow area represents the area that is accessible in about the same amount of time as before from the blue pin. The blue area shows the area that was previous accessible within 60 minutes, but will be reachable more quickly than before and the purple area shows the parts of the city that will newly be reachable within 60 minutes once the project is complete. This information allowed the World Bank to evaluate the economic impact of the project more clearly quantifying the travel time savings for people in the city (World Bank, 2015).

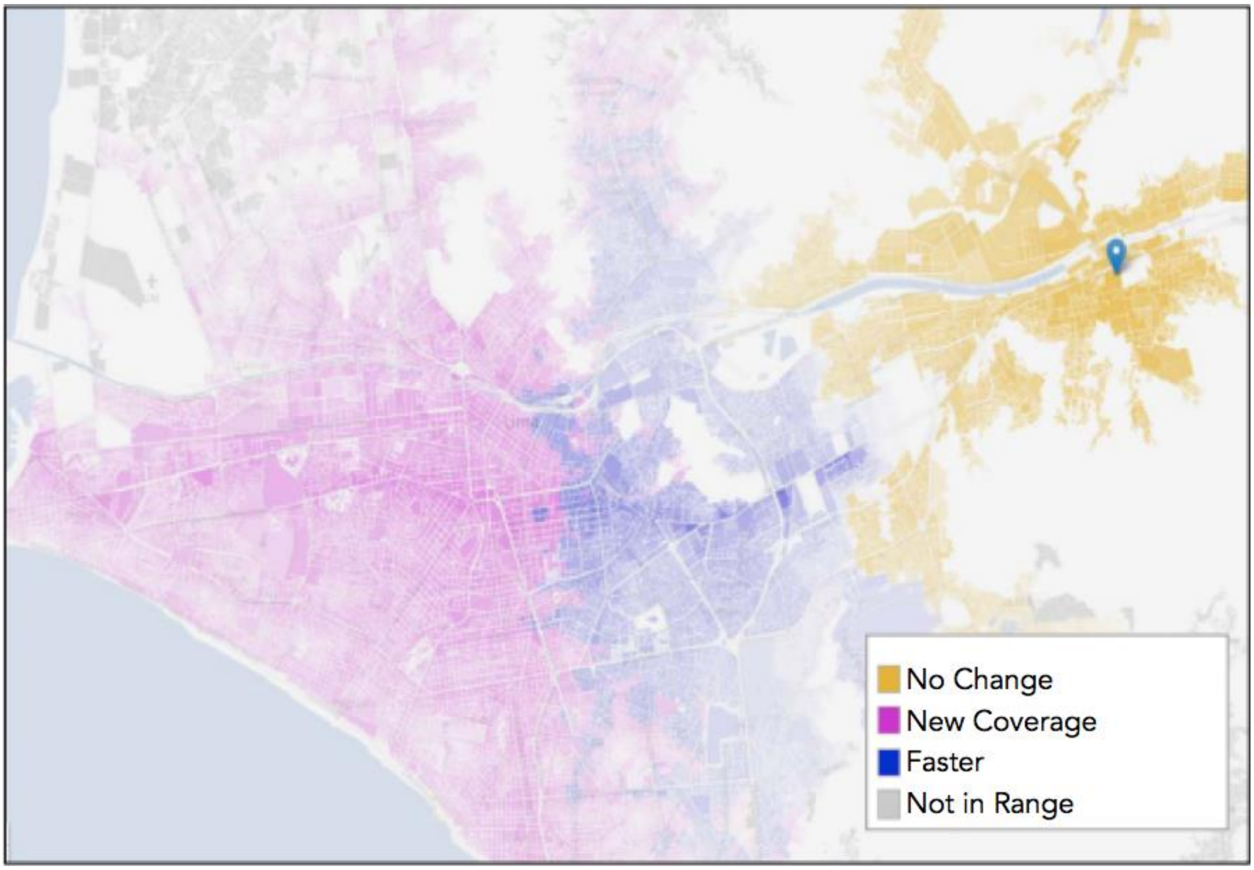


Figure 8: Example from World Bank report on new transit alignment: Employment catchment areas for 60-minute commute trips from a selected location in Ate District.
Source: World Bank, 2015, p. 85; Map Data: Household Travel Survey (2012) and INEI data, processed by World Bank

The World Bank used the accessibility measure based on the premise that the project should maximize the improvement in access to jobs, but in transit service planning it is important to take a more nuanced view of transit service that requires balancing competing priorities. A common example of such dichotomies is commonly known as “ridership versus coverage” (Walker, 2012). This phrase refers to the notion that transit agencies have limited resources and sometimes decisions must be made to prioritize one goal at the expense of another. As an example, a transit agency may need to decide whether an additional bus should be used to reach an unserved, sparsely populated neighborhood or whether the additional bus should be used to relieve crowding on a busy transit corridor. This concept is most commonly used to refer to coverage in the geographical sense to indicate perhaps whether a community has access to a bus stop, but this thesis more deeply explores how this concept of coverage could refer to the provision of transit service through the course of the day.

Recent work by Steven Farber (2016) has put forward the idea of a standard "public transit travel time cube" which refers to a set of origin-destination matrices representing many times of the day that are populated by travel times between the points (see Figure 9). The authors developed the travel time cubes to evaluate the before and after impact of service cuts and additions in Portland, Oregon and the Salt Lake City, Utah region. Farber does an in-depth statistical analysis of the travel times to and from CBGs before and after the service changes. The research goes far beyond simply looking at how much travel times improved, but additionally measures consistency of travel times over the course of the day in each CBG. The travel times that are used in the analysis span the length of a weekday and are weighted by the population in the population in the CBG at the trip origin. It notable that most of the analysis is done on travel times to all destinations and therefore there is no weight given to the value of different destinations. After the analysis of travel times, there is an evaluation of how the service change impacted access to jobs during the peak period between 7 AM and 9 PM (Farber, 2016).

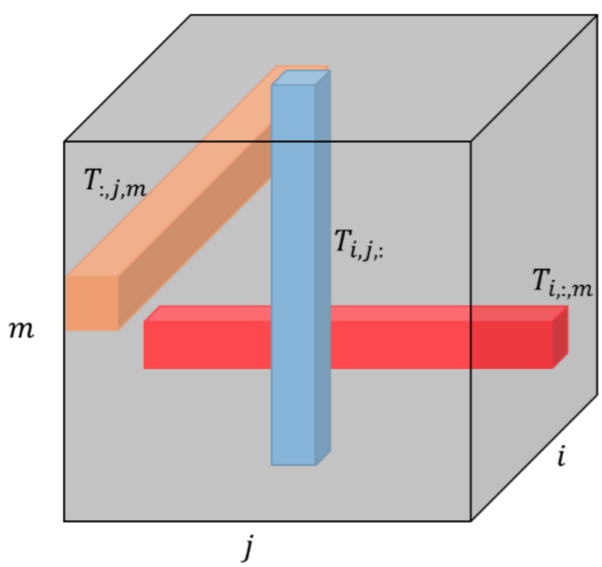


Figure 9: " Illustration of the travel time cube and its atomic vectors. The axes represent origins (i), destinations (j), and minutes of the day (m). Each location in this three dimensional matrix contains a shortest path travel time from i to j at time m." (Farber, 2016, pg. 8)

3 Research Design and Methodology

This thesis focuses on evaluating recent service improvements that were implemented by the New Orleans Regional Transit Authority (RTA) in the spring of 2016. With the exception of the work described by Farber, et. al. in 2016, all of the accessibility analyses that have been researched in the literature review were geared towards evaluating the difference in access between different cities and different neighborhoods. UMAO and the World Bank have published their accessibility analyses that were performed in conjunction with new major rail projects. The methodology that is used to answer the research questions of this thesis draws heavily from these different examples, but differs because it is takes a more detailed look at access to jobs over the course of the day.

UMAO's methodology for evaluating access was based on a rather narrow period between 7 AM and 9 AM, but service changes are very often focused on improving access to jobs at a specific time of day. New Orleans is famous for its vibrant late-night economy and the RTA recently reconfigured their service to provide all-night service on eight transit lines. The RTA also added a new line to the airport from downtown with 90-minute headways and increased the frequency of 15 different transit lines. This service change would increase operating costs for the RTA by $4 million (Rainey, 2016). This thesis aims to determine the best way to evaluate changes in the access to jobs that would appropriately factor in this late night service or perhaps any service change. To do this, three different methods of analysis were used to calculate the average number of jobs accessible under the two different service scenarios. The essential output from this analysis is a large dataset that resembles the "travel time cube" developed by Farber et. al. (2016), but instead of travel times populating the cube, it will be the number of jobs accessible in 30 minutes.

3.1 Data Sources

3.1.1 Transportation networks

3.1.1.1 GTFS

RTA makes GTFS data available through their website and publishes updates in advance of any service update. Jefferson Transit does not make their GTFS information available to the public and I developed a GTFS feed independently using their online maps and schedules from 2014. St. Bernard Transit is more challenging because their stop locations are not available through Google Maps and they additionally offer deviated fixed route service that does not easily conform to the conventions of GTFS.

3.1.1.2 OpenStreetMap

Transportation network data was provided by an OpenStreetMap New Orleans-Metairie metro extract in Protocolbuffer Binary Format, which was provided by Mapzen. This includes the roadways and other features of the transportation network along with characteristics indicating road speed and whether cyclists and pedestrians may access it. OpenStreetMap is a collaborative project and it depends on volunteers to keep the content up to date (OpenStreetMap.org)

3.1.2 Census Data

3.1.2.1 Longitudinal Household-Employer Dynamic

The Longitudinal Household-Employer Dynamic (LEHD) Origin-Destination Employment Statistics (LODES) are a rich dataset available through the US Census Bureau that provides the locational information for jobs and workers. This analysis used residence area characteristics and workplace area characteristics files to identify how many workforce participants work and live in each census block.

3.1.2.2 American Communities Survey

Data from the US Census Bureau's 2010-2014 American Community Survey (ACS) 5-Year Estimates provided information on what time people in New Orleans leave home to go to work.

Table 1: Time leaving home to go to work: Orleans Parish workers over 16 who did not work at home

	Estimate	Margin of Error
12:00 a.m. to 4:59 a.m.	5,340	+/-509
5:00 a.m. to 5:29 a.m.	4,359	+/-455
5:30 a.m. to 5:59 a.m.	5,335	+/-482
6:00 a.m. to 6:29 a.m.	13,078	+/-694
6:30 a.m. to 6:59 a.m.	13,502	+/-812
7:00 a.m. to 7:29 a.m.	23,295	+/-896
7:30 a.m. to 7:59 a.m.	18,872	+/-769
8:00 a.m. to 8:29 a.m.	19,239	+/-785
8:30 a.m. to 8:59 a.m.	10,252	+/-605
9:00 a.m. to 9:59 a.m.	11,477	+/-653
10:00 a.m. to 10:59 a.m.	5,647	+/-425
11:00 a.m. to 11:59 a.m.	2,041	+/-302
12:00 p.m. to 3:59 p.m.	11,720	+/-712
4:00 p.m. to 11:59 p.m.	11,917	+/-655
Total:	156,074	+/-1,747

Source: US Census Bureau's 2010-2014 American Community Survey (ACS) 5-Year Estimates

3.2 Study Area Geography

This study was performed in New Orleans, but identical methodologies could be used to evaluate the transit network of any region in the world that has the necessary data available. The analysis will look at the jobs accessible to residents of Orleans Parish in the three parishes that are served by fixed route public transportation: Jefferson Parish, Orleans Parish, and St. Bernard Parish. The original plan was to use census blocks as the basis of the analysis because that is the smallest unit for which LODES data is available and it would provide for more accurate travel times for residents and offer a higher resolution to the data. However, there are nearly 15,000 census blocks in the study area, thereby creating 225,000,000 ($15{,}000^2$) potential trips, which the available hardware was unable to calculate in a reasonable amount of time. Instead, CBGs are used because there are only about 900 in the study area, requiring the calculation of a more reasonable 810,000 trips.

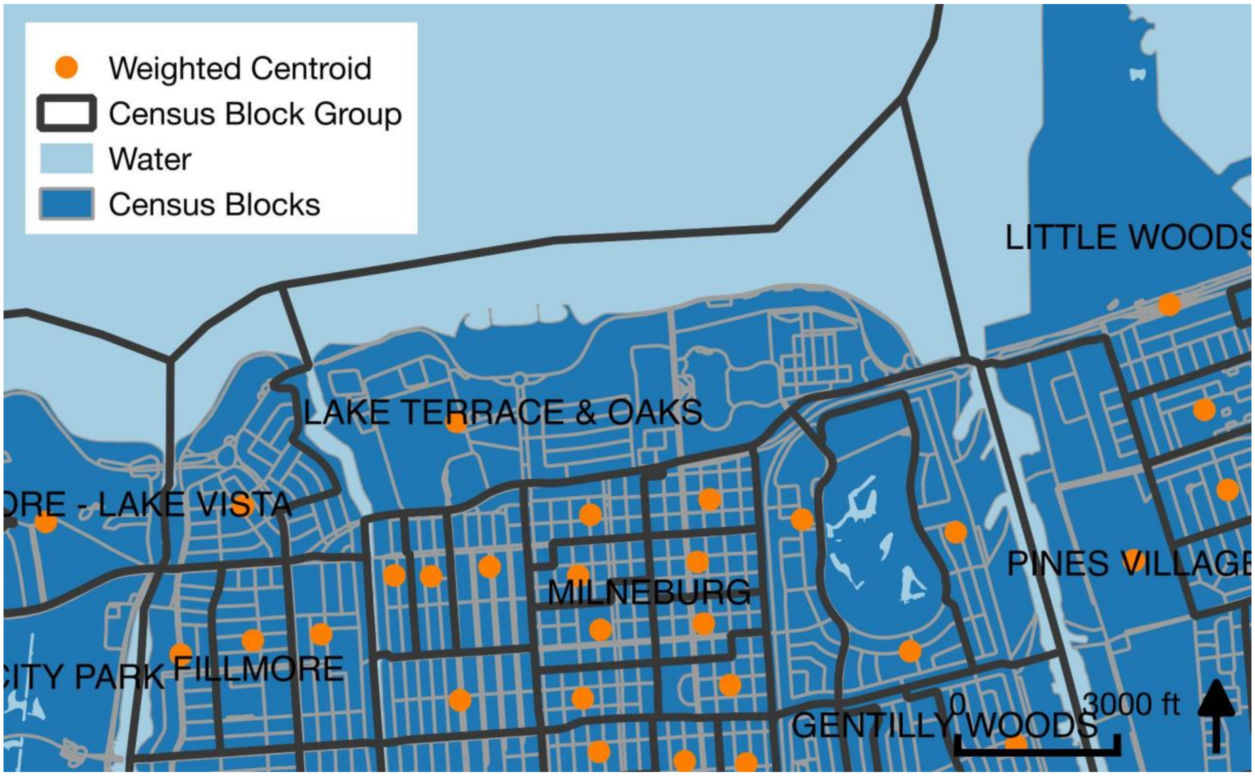


Figure 10: Example of weighted centroids within study area
Source: US Census Bureau; LODES

To determine the trip origin location to be associated with each CBG I used a centroid weighted by the number of jobs and workers residing in the census blocks that compose the CBG using QGIS. This helped to prevent trip origins and destinations from appearing in water or inaccessible portions of the CBG. Figure 10 demonstrates how the weighted centroids in many cases are clearly not located in the geometric center of the CBG, but instead tend to be located closer to densities of jobs and residential development. One issue with using the CBG designation is that the geographical size of each unit is based partly on population. As a result, certain CBGs that have very high concentrations of jobs will be geographically very large because there aren't many people living in the same area. This can cause a reduction in the level of precision for travel times. For example the Central Business District neighborhood of New Orleans has the densest concentration of jobs in the city, but it doesn't have very many residents so much of the area is composed of only one CBG. As a result if it is possible to reach that singular point from an origin in 30 minutes, there is a disproportionately large increase in the apparent number of jobs that are accessible from an origin that takes 31 minutes to reach the single point.

3.3 Opportunities

The decision to only evaluate jobs instead of another destination such as schools or hospitals was based on the premise that this project is primarily intended to serve as a demonstration of accessibility concepts and evaluate methodological differences in the techniques used. It is not intended to serve as an analysis of the effectiveness of transit in the New Orleans MSA. Job access serves this objective well because there are lots of jobs in the community and they are more geographically dispersed than most other destinations that are not as numerous. Additionally, workplaces are usually co-located with many typical travel destinations. i.e. most of the trips that people make are not to work, but major centers for shopping, healthcare, education and recreation often also correspond with substantial centers of employment (Hanson, 2004). While jobs are not intended to serve as a total and complete proxy for these non-employment destinations, they are a simple and diverse representation of typical destinations. Furthermore it is possible to study a subset of jobs and workforce members such as jobs in a particular industry or low-income workers, but this thesis is primarily focused on providing a general overview of the temporal component of access rather than a more robust analysis of inequity in transit systems.

3.4 Trip Planning Technology

There is software available that allows researchers to evaluate accessibility metrics with varying levels of detail. For example, Conveyal is among the most well known software developers in the industry and they are a major contributor to several open source public transportation tools, including OpenTripPlanner (see section 3.4.1) that they use to provide consulting services to client. Conveyal also offers a software as a service called Transport Analyst that can provide accessibility data that is tailored to the user's needs and can be used through a web service that does not require programming experience. However, the goal of this thesis is to provide a detailed methodological overview of accessibility metrics and it is therefore more practical (and less costly) to break the process down into its component steps by using a collection of free, open source software packages.

3.4.1 OpenTripPlanner

OpenTripPlanner is the routing software that was used to calculate travel times between two points. To do this the software combines OpenStreetMap and GTFS Data to build a "graph." The graph allows users to calculate travel time between points within the graph's extents using any preferred combination of walking, biking, driving, or transit. The OpenTripPlanner API makes it possible for users to develop custom python scripts (See Appendix B) to calculate travel times between points based on a large number of variables, including mode(s) and departure time. Using this technique, I calculated travel times for trips between every census block group in the study area, every ten minutes, throughout the course of a typical weekday.

3.4.2 R Studio

R is a free, open-source data analysis program that allows users to write scripts to process large datasets and document the procedures. R Studio is a free program that creates a more straightforward user interface for the software. It was used in this analysis to connect trip travel times between CBGs to LODES data for the CBGs, calculate population-weighted average of job access from CBGs, and export datasets that could be loaded into spreadsheet and GIS software for creating graphical representations (See Appendix A). R is capable of performing similar visualizations, but the author is not experienced in these methods.

3.4.3 QGIS

QGIS is open-source, free software that was used to create population- and job-weighted centroids of CBG to serve as trip origins and destinations and create graphical representations of the accessibility analysis.

3.5 Temporal Component

The primary objective of this thesis is to examine how evaluating travel during different times of day might influence the duration of trips that form the basis of the accessibility analyses. OpenTripPlanner was used to calculate the travel time between the approximately 900 CBGs at 10 minutes intervals for two different GTFS feeds that represent the two different service scenarios that were being compared. The first GTFS includes dates from September 9, 2015 to January 9, 2016 and is referred to within this thesis as "2015." The second GTFS includes dates from May 29, 2016 to September 3, 2016 and is referred to within this thesis as "2016." The result is two sets (each GTFS) of 144 (10-minute intervals over 24 hours) origin-destination matrices, each composed of approximately 810,000 travel times (900 CBGs squared). Three different analysis techniques were used to manage the temporal component of this data. The first technique, known as "Peak," only includes travel time observations during the morning peak travel period, from 7 to 9 AM because that is when most commuters leave for work and is the same methodology used by UMAO as discussed in section 2.3.2. The second technique, "All Day" is identical except for that it includes the average over all 24 hours of weekday service. Finally the third model, "Dynamic," is a gravity-based metric that weighs access at different times according to the percentage of people commuting during that period and is the same method used by Legrain (2015).

The ACS provides information that indicates what time people leave home for work in increments that vary from 30 minutes to as long as 8 hours. As a result it was necessary to reconfigure the percentages into 10-minute increments to match the data provided in the accessibility analysis. For example if the ACS estimates that 15% of commuters leave home during a 30-minute period, each travel time observation during that period, at 10-minute intervals, would carry 5% of the weight in this model. Figure 11 shows how each time period is weighted through the course of the day along with the corresponding number of jobs available at each time of day.

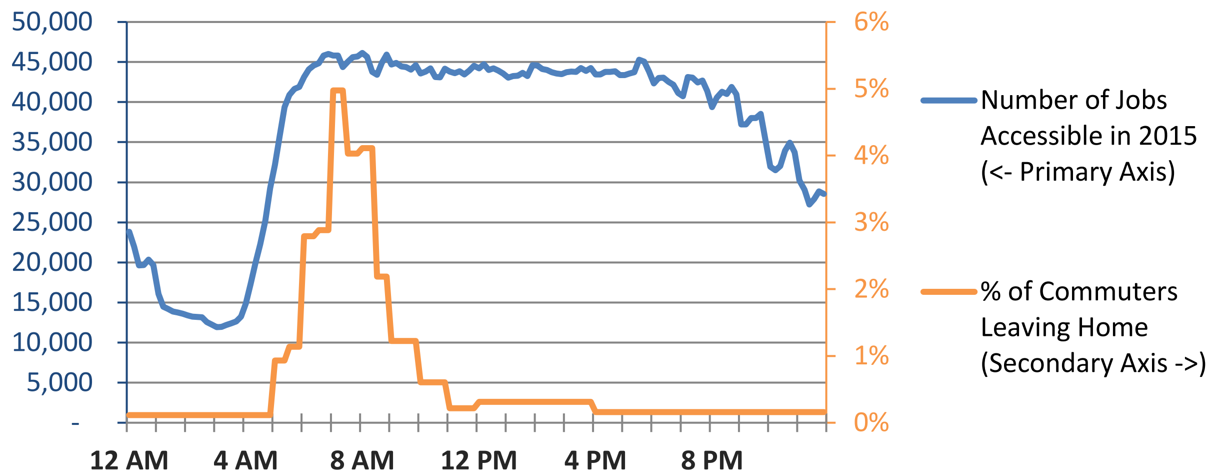


Figure 11: The orange line represents the percentage of all commuters that are leaving home to go to work during 10-minute-long periods. The blue line indicates the average number of jobs that are accessible on public transportation and walking by time of day.
Source: US Census Bureau, American Communities Survey 5-year Estimates, 2010-2014

3.6 Aggregating Data

As described in section **Error! Reference source not found.**, access is typically calculated for a single point, but for this study it is valuable to aggregate this data into a single figure that represents the average number of jobs that New Orleanians can access. The following formula describes how the weighted average is calculated:

Weighted Average = $(w_1/a)j_1 + (w_2/a)j_2 \ldots w_n/a)j_n$

w = workers residing in CBG; a = all workers residing in the study area; j = jobs accessible from CBG; n = Each CBG in the study area

3.7 Limitations

Travel times in GTFS are based on perfect schedule adherence. As a result, if on-time performance for the agency is very poor, actual travel times for an agency will usually be longer. GTFS data was not universally available for the region. St. Bernard Parish includes about 2.6% of the region's jobs, but because there was no GTFS data available for the transit line there, resident's ability to access that employment was undercounted. Jefferson Transit has had minor service changes since the time when this GTFS was developed, but the focus of this thesis was to evaluate impact of RTA service changes so the nuances of changes in Jefferson Transit are less relevant.

OpenStreetMap data is very good, but no map is perfect and contains all of the data possible, and that is especially true with regards to pedestrian networks. OpenStreetMap's process for editing and updating network data is transparent and anyone can perform modifications either for the source data or for their own purposes. However, there are inevitably shortcomings; many streets that are assumed to have pedestrian access may be unsafe for a variety of reasons and small pedestrian pathways can sometimes connect vehicular roadways without any documentation.

Other analyses use smaller geographies and job opportunities from a greater distance beyond the study area. This sort of analysis provided more granularity and guaranteed the inclusion of every possible job opportunity. However, this would have required much more computing power and the associated financial cost of high power computing resources was not within the budget for this thesis.

A 30-minute travel time threshold creates an artificial barrier that indicates a job accessible within 29 minutes is valuable, but a job accessible within 31 minutes is not. The UMAO overcame this limitation by calculating access for multiple thresholds and using a gravity-based technique to weigh jobs more heavily if they are a shorter travel time from the trip origin. This thesis is primarily focused on observing different times of day to evaluate access and creating a gravity-based model would have added unnecessary complexity to this goal.

4 Results and Analysis

The first question of this thesis was whether this accessibility analysis could be boiled down to a single metric that could be used by stakeholders to determine the value a service change, and that soon leads into more complex questions about how accessibility measures can guide the planning process and evaluate the cost effectiveness of service scenarios. The results of this analysis clearly show that the $4 million increase in operations spending by the RTA had a significant impact on access to jobs in New Orleans, particularly late at night. This section will discuss how the chosen methodology can illuminate the impacts of those changes. It will also discuss the role of accessibility analysis in transit service planning.

1. Can a simple accessibility metric be used to evaluate transit service changes?

Many transit agencies implement service changes once or twice every year and it can be very challenging to determine what the impact of the changes will be on a collective basis. The ability of transit riders to transfer between routes and use multiple different transit lines that will reach the same destination can be extremely complicated and confusing. This thesis aims to answer whether it might be possible to summarize the basic effectiveness of a service scenario with one of the three different metrics that are referred to as All Day, Peak, and Dynamic. These metrics are used to evaluate access for every individual census block group (CBG) and then to form an average across the city. Table 2 provides a review of what these three metrics are.

Table 2: Brief description of accessibility metrics

Metric Name	Time range	Weighting
All Day	24-hour; weekday	None
Peak	7 AM to 9 AM; weekday	None
Dynamic	24-hour; weekday	Daily commute patterns

When the RTA announced recent service changes through media outlets, they characterized them as a substantial increase in transit service that would provide more service late at night (Rainey, 2016). Most of the job access metrics that have been used in the past focus on the peak AM commute period and it is obvious that a single metric of access that is based on the peak period is not useful, but it is included as a metric in this review to provide a basis of comparison.

Table 3: Impact of service level Changes on job accessibility for Orleans Parish residents.

	All Day	Peak	Dynamic
2015	36,483	45,181	43,077
2016	40,724	45,139	44,471
Change	11.6%	-0.1%	3.2%

Source: RTA, Jefferson Transit, OpenStreetMap, LODES, ACS.

As can be seen in Table 3, the three different metrics had enormous differences in the number of jobs that were reported as accessible and the change that occurred following the service increase were very different. The service changes did not offer any change in access levels during the peak AM commuting period, which confirms that the late night service changes had little impact past 7 AM (see Table 3). This trend is further reflected in Figure 12 where it can be seen that between the hours of 7 AM and 9 AM the levels of access are very similar. Where 2015 and 2016 service levels clearly depart is in the evening and early morning hours. The 24-hour “All Day” metric values access the same way no matter when the travel time calculation is observed and for that reason it reflects the greatest increase in service between service levels. Finally, the “Dynamic” metric, which weighs the time of day in proportion to the number of people commuting within Orleans Parish, estimates access for Orleans Parish residents to have increased by 3.2%. As would be expected, this is somewhere in between the two other metrics.

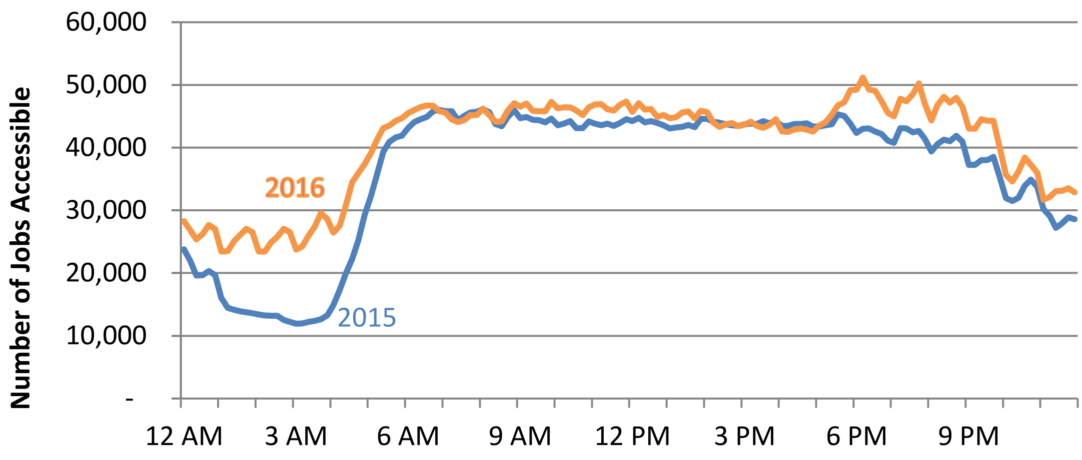


Figure 12: Average access to jobs under 2015 and 2016 service levels for Orleans Parish residents
Source: RTA, Jefferson Transit, OpenStreetMap, LODES.

The Peak metric clearly failed to summarize the impact of service changes but the All Day and Dynamic metrics offer potential as a simple way to evaluate the effectiveness of service changes, but they also highlight the fact that public transportation has competing goals and it is difficult to simultaneously evaluate all of them. However, the Dynamic metric begins to reveal how weighting can allow a transit agency allow their priorities to influence an accessibility metric. For example, across the city most people commute to work early in the morning, but there may be certain neighborhoods where that is not the case. Indeed research indicates that high- and low-income transit commuters have different peak commute periods (Legrain, 2014). It would be possible to Census data and surveying to define a demand curve by time of day for each neighborhood in the city that could allow the RTA to plan for the needs of each neighborhood differently. Another possibility would be to address concerns relating to social equity by evaluating the average number of jobs accessible to disadvantaged populations before and after the service change. Finally, coverage has typically been evaluated by looking at the percentage of the population that lives within a quarter mile of a bus stop. Perhaps using accessibility metrics, it would be more beneficial to evaluate how many jobs are accessible to the first or second decile of CBGs. There are a total of 878 CBGs in Orleans Parish and Table 4 indicates that the 88 (first decile) least accessible CBGs had access to 1,796 jobs or less in 2016. This is six fewer than in 2015 and show that the service changes did little to improve transit service for the population of Orleans Parish that is most poorly served.

Table 4: The distribution of jobs accessible from CBGs based on the All Day metric by decile.

Decile	2015	2016	Change
1st	1,802	1,796	-6
2nd	4,320	4,558	239
3rd	6,565	7,095	530
4th	9,898	11,284	1,386
5th	13,916	18,106	4,190
6th	23,745	26,061	2,316
7th	34,185	37,643	3,458
8th	53,952	62,494	8,542
9th	77,302	83,458	6,157
10th	120,025	125,835	5,810

The accessibility metrics that cover the full 24-hour span of service in New Orleans did a good job of indicating the that there was an improvement in transit service, and it probably does a better job of measuring the effectiveness of a transit service change than most other individual figures. Alternative metrics that could be used to evaluate transit service include revenue hours, ridership, or simple travel times instead of accessibility as an aggregated metric of a transit system, but they all have drawbacks. Revenue hours only indicate that a bus is in service, but there is not any clear indication that the service is useful. Ridership is difficult because it cannot be evaluated until the service change has been implemented and also sometimes the ridership effects of a service change can take a long time to be measurable because of economic and seasonal cycles. Farber, et. al. (2016) did much of their analysis on simple travel times that did not weight the value of the destinations, and therefore may value access to wilderness equally with access to a busy shopping district. Overall there is not a single number that will comprehensively evaluate a transit system's performance, but accessibility metrics seem to get closer than anything else.

2. How can accessibility analysis be used to assist in developing schedules during routine transit service changes?

The average of job access across the city offers a very simplified look at how a transit network functions, but transit service planning requires a more detailed review of the data that an aggregate metric cannot capture. For instance, someone might conclude that if the average resident has improved access to jobs, the network change was positive. However, different areas across the city have widely varying access to jobs, which is illustrated in Figure 13 and Figure 14. It can be seen that there is clearly a downtown area where access to jobs is the greatest and then there are appendages that point out from downtown along certain transit lines that offer the greatest mobility. However, many areas that are more distant from the downtown area do not have strong access to jobs.

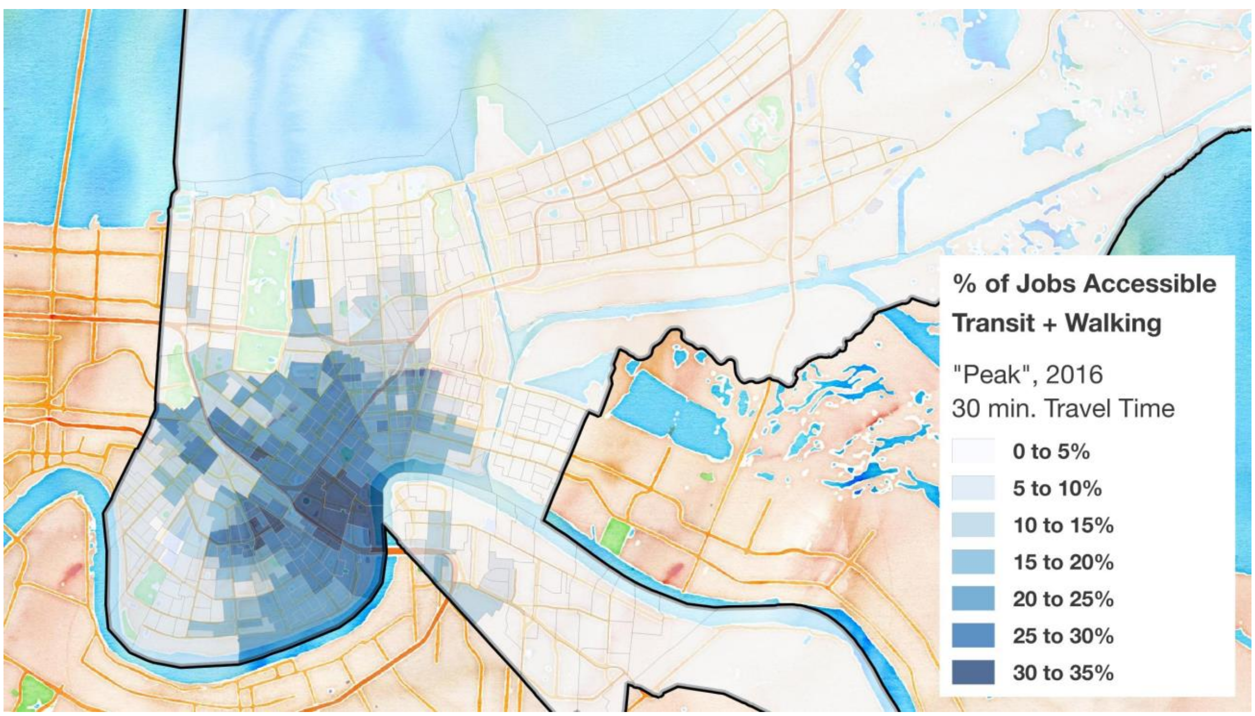


Figure 13: Average percent of study area jobs accessible on transit and walking between 7 AM and 9 AM.
Source: RTA, Jefferson Transit, OpenStreetMap, LODES. Map Data: US Census Bureau, OpenStreetMap Contributors.

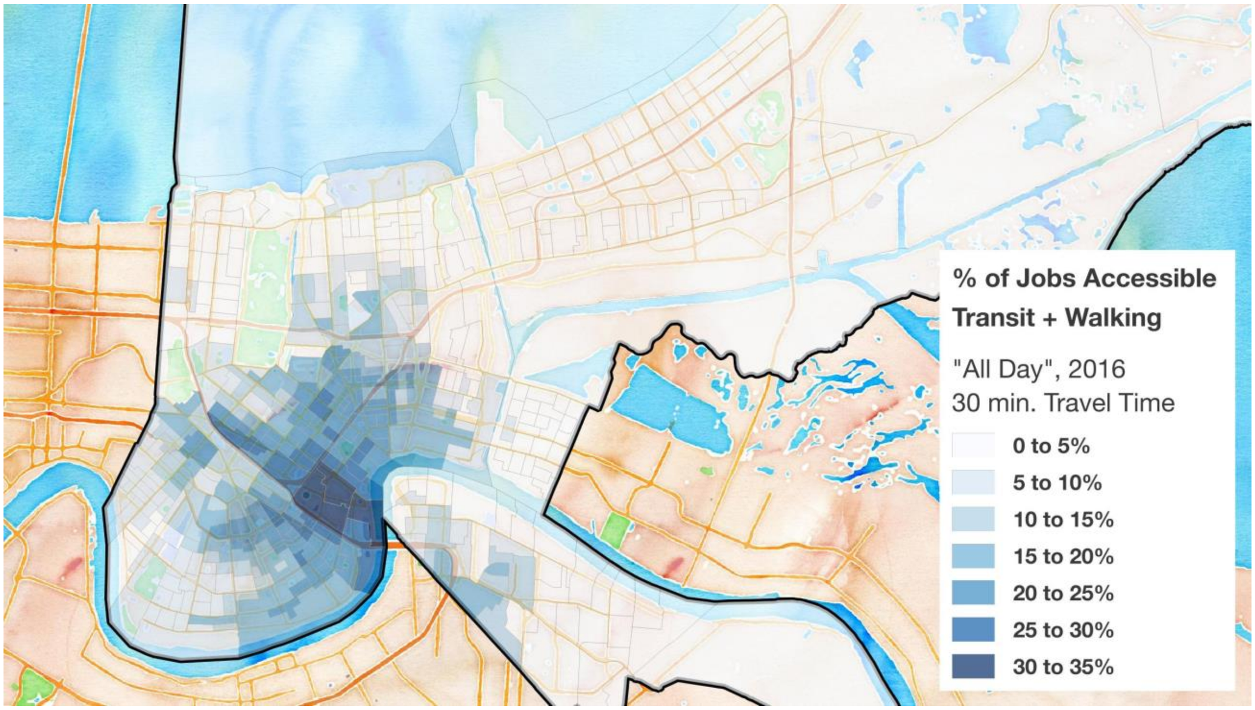


Figure 14: Average percent of study area jobs accessible on transit and walking over 24 hours.
Source: RTA, Jefferson Transit, OpenStreetMap, LODES. Map Data: US Census Bureau, OpenStreetMap Contributors.

Figure 13, Figure 14, and Figure 15 provide a detailed view of how methodologies focusing on the “All Day” and “Peak” periods influence the outcome of this analysis. Just as access to jobs on transit is not evenly distributed across the city, access to jobs is distributed differently over the course of the day depending on where you live. Figure 15 indicates that surprisingly many parts of the city apparently have better access to jobs in the “All Day” metric than the “Peak” metric. This is surprising because as discussed in section 3.1.2.2, the ACS data indicate that overall, the greatest number of people commute between 7 AM and 9 AM and this is therefore the period during which most people want good transit service for their trip to work.

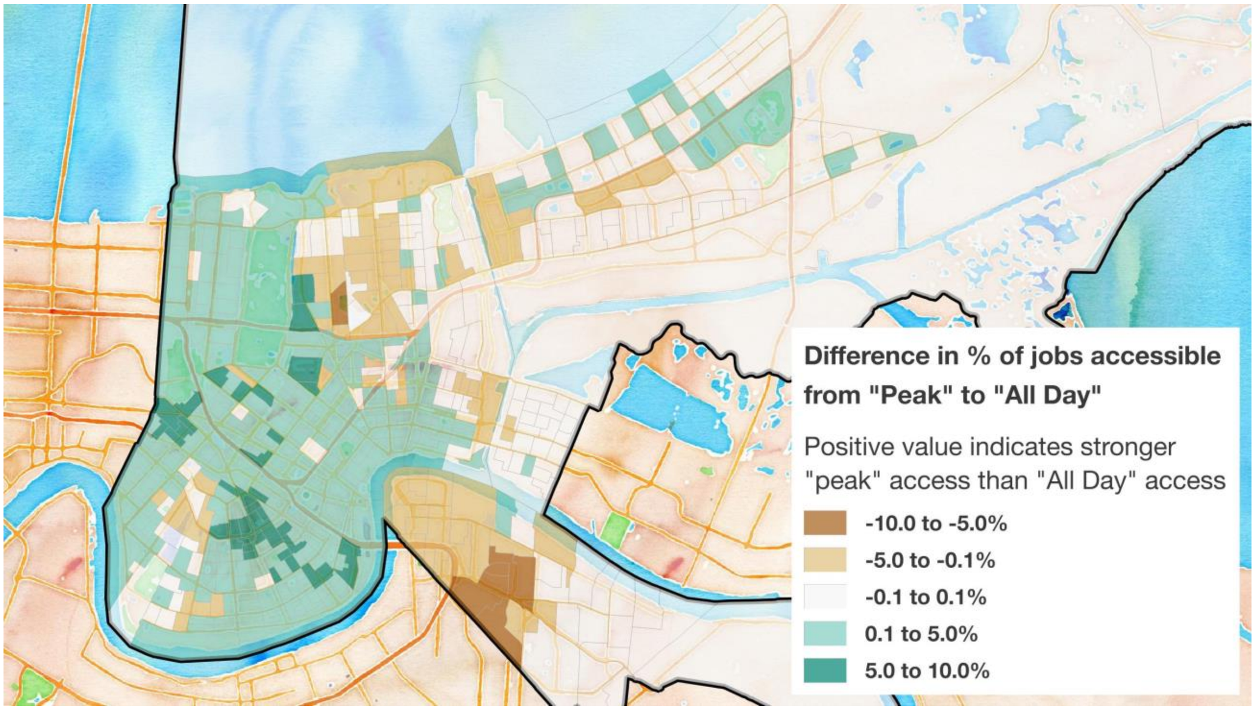


Figure 15: Illustrates the percent of jobs accessible at "Peak" minus the percent of jobs accessible "All Day."
Source: RTA, Jefferson Transit, OpenStreetMap, LODES. Map Data: US Census Bureau, OpenStreetMap Contributors.

Evaluating a single CBG offers some insight into why certain CBGs have better access to jobs over a 24-hour period than during the peak period and also how the variance in transit access over the course of the day manifests itself on the ground. Figure 16 shows how dramatically levels of access vary based on transit schedules and incidentally it also demonstrates the importance of transit to many residents that do not own cars. CBG 220710006031 is within the Behrman neighborhood on the west bank of New Orleans and this is part of the area that in Figure 15 appeared to have poor access to jobs at the AM peak compared to the rest of the day. In Figure 16 it can be seen how dramatically access to jobs varies through the course of the day and it is easy to imagine the dramatic spikes in access at the moment when a bus finally passes near the trip origin. It is also very striking that from this census block group, residents seemingly have better access to jobs from 3 AM to 6 AM than any other time of day. This is in stark contract to the lull that appears in the late afternoon when apparently no buses are available.

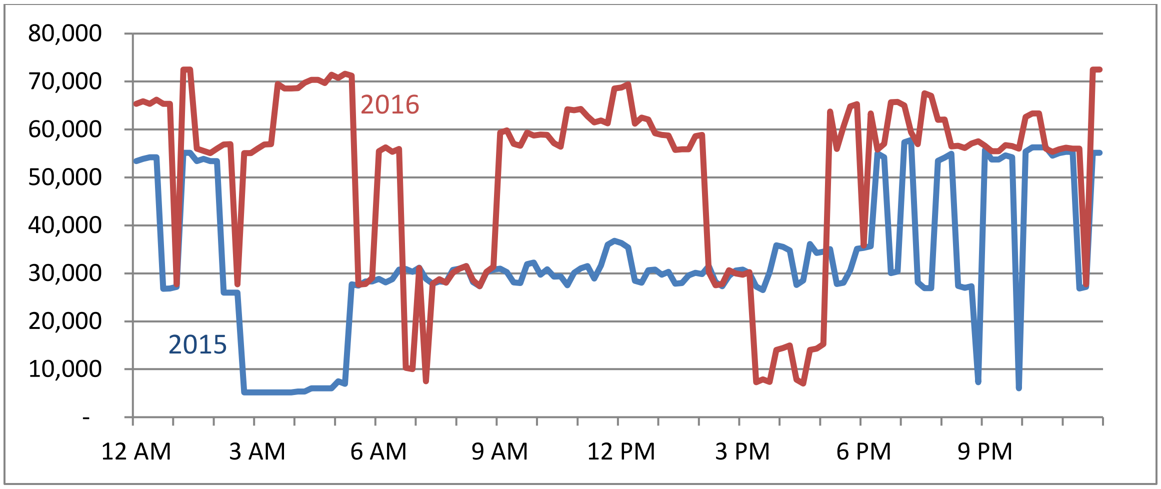


Figure 16: Average access to jobs under 2015 and 2016 service levels for residents of CBG 220710006031.
Source: RTA, Jefferson Transit, OpenStreetMap, LODES.

Taking a deeper looks into the case of this CBG shows that this is an area that is served by five different bus lines that travel downtown. Through a quirk of scheduling this neighborhood has four buses that depart for downtown between 6:55 and 6:59 AM—just a few minutes before the 7 AM beginning of the peak period. Then in the following two hours there are only 6 buses that serve the same stop. Table 5 confirms what can generally be observed in Figure 16; transit has improved overall for the CBG, but there is an untimely lull in service during the peak period, which causes job access levels to diminish based on the "Peak" metric. This analysis indicates that it would potentially be beneficial to stagger the departure of buses from the Behrman neighborhood differently so that there is less duplication of service on this corridor and a more even distribution of departure times to the downtown job center.

Table 5: Impact of service level changes on job accessibility for residents of CBG 220710006031.

	All Day	7 AM to 9 AM	Dynamic
2015	32,457	29,507	29,933
2016	50,910	27,783	38,902
Change	30.0%	-5.8%	30.0%

Source: RTA, Jefferson Transit, OpenStreetMap, LODES, ACS.

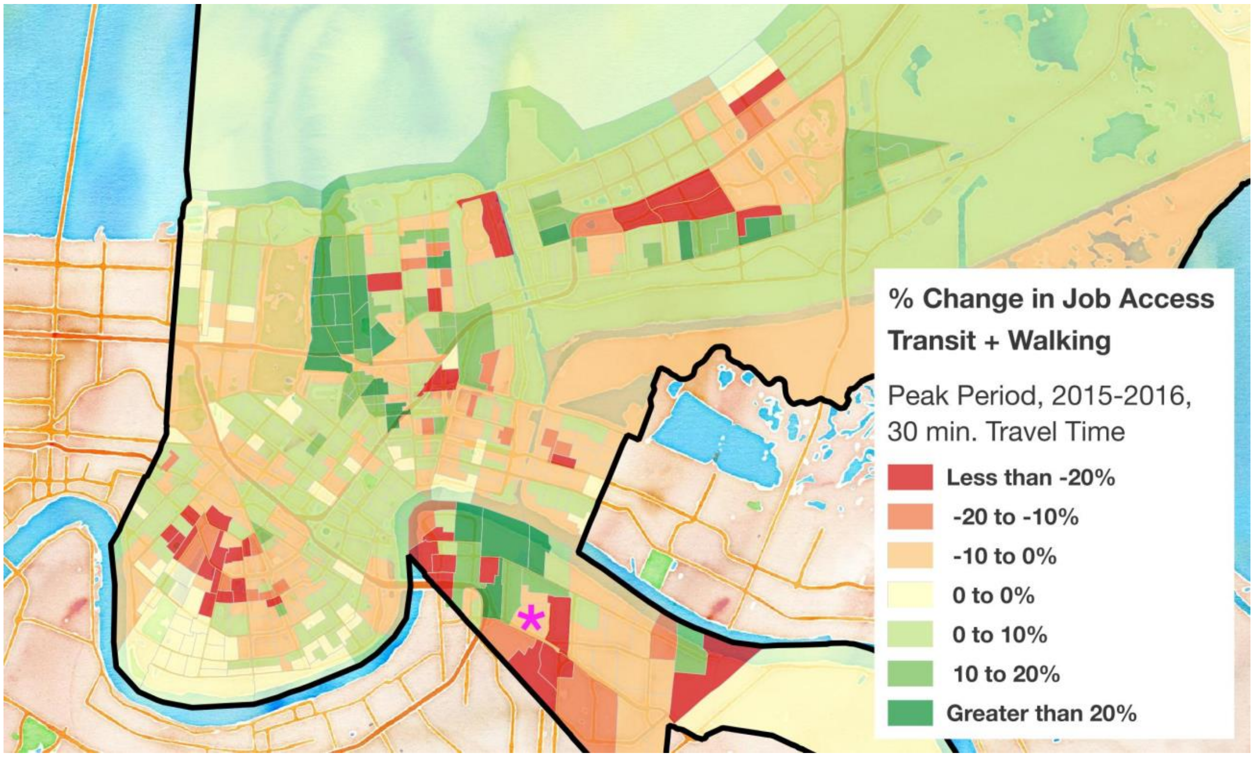


Figure 17: Percent change in the number of jobs accessible in the number of jobs accessible from 2015 to 2016. Pink asterisk indicates the weighted centroid for CBG 220710006031 in the Behrman neighborhood.
Source: RTA, Jefferson Transit, OpenStreetMap, LODES. Map Data: US Census Bureau, OpenStreetMap Contributors.

Looking at accessibility across the city during the peak period did not show any significant change in accessibility, but that was clearly untrue in the case of CBG 220710006031 (the Berhman neighborhood) and there are many similar cases in other areas of the city. Figure 17 shows that many neighborhoods had significant shifts in their access to jobs during the peak period. Some areas had access to more than 20% additional jobs during this period and some neighborhoods had the number of jobs they could reach reduced by more than 20%. However questions remain as to whether access during the peak period was truly diminished in these locations or if there was just a slight shift in the schedules. This accessibility analysis could be an extremely useful tool in scheduling because it highlights the inconsistencies in access throughout the course of the day. Farber, et. al. (2016) have developed some tools to evaluate similar inconsistencies based on travel time averages, and similar techniques could be used by transit schedulers to flag problem areas and times of day.

Transit service planning is an exercise in allocating scarce resources and accessibility analyses could be especially effective in the prioritization and decision making process for transit agencies as they develop service changes. As discussed in response to the first research question, the average accessibility should not be the sole metric used in the evaluation, but it can be very effective when considering where service should be cut or increased. For example, the RTA recently put a new streetcar line into service and requested public input on two proposals for how bus and streetcar service would be modified as a result (Rainey, 2016b). This would have been a natural case in which the RTA could have evaluated the how job access would be impacted by the two different proposals.

However, the limitations of the methods that are presented here are very clear and there is a great deal of room to improve upon them. One of the service changes between the 2015 to 2016 scenarios was the addition of an express bus during the peak between the airport and downtown. This line would connect between two major job centers at the new airport construction site and downtown New Orleans. However the travel time is over 30 minutes so it didn't have any impact on the peak travel period even though it will certainly have some positive impact on residents' ability to reach jobs. A better technique would be to incorporate the research of UMAO and Farber et. al. (2016) to perhaps evaluate several travel time thresholds ranging in length from 10 to 60 minutes or use a gravity-based model that incorporates all travel times but weighs nearby job more heavily.

3. Can accessibility analysis be used to measure progress towards the goals of public transit in a community?

Public transportation is beneficial to communities because it can reduce pollution, congestion, and transportation costs, and many people would instinctively suggest that success in providing those benefits is signaled by increased ridership. However, in section 2.4.2 the ridership versus coverage dilemma was introduced with the example of an agency deciding whether to allocate resources toward providing transit service to an unserved neighborhood or to relieve crowding on a busy route. This final question aims to see whether accessibility analysis can be used to untangle some of these complex objectives and evaluate how a transit agency is moving toward their different goals. Some transit agencies may make it a particular priority to provide transit service to disadvantaged populations and accessibility analysis could be used to focus on the extent to which a transit agency is achieving that goal by comparing levels of access among individuals in specific demographic groups against the overall average. This thesis primarily focused on the variance in levels of access during the course of the day so it was possible to see that RTA was providing public transportation as an option for late-night workers with their most recent service change. If an increase in ridership had been the sole objective of the RTA, they probably would have taken on a different strategy. However, a key question in determining the usefulness of these accessibility metrics is whether it correlates with transit ridership.

Much of this thesis was predicated on the premise that when access to destinations is improved on public transportation for a specific population, there will be a resulting increase in ridership. This is because ridership projections are often based on an evaluation of the same factors that lead to strong access to jobs, traits such as frequency, coverage, population density, and revenue hours (Taylor, et. al., 2003). Research also demonstrates that there are factors that predict transit ridership that are not included in an accessibility analysis such as fare pricing, parking costs, transit schedule adherence, or the proportion of residents that do not own a car. This research suggests that it may be possible to predict future system ridership by appropriately weighting access that is provided to residents that possess traits that are typical among those that are more inclined toward riding transit. The ability to travel to a job by private vehicle or some other mode is also a strong predictor of whether people will use public transportation so it may be important to compare access to jobs with public transportation with access on foot or by private vehicle (Taylor, et. al., 2003). For example, a very compact, affluent town may be able to easily create a transit system that provides high levels of access to jobs, but if it’s also very easy to walk and drive, people may not choose public transportation in the end. Further research would clearly be needed to research the best techniques for predicting ridership based on these techniques and also to determine how predictive they can actually be without including a variety of other factors that play into people's decision to ride transit. Accessibility metrics can provide insight into whether public transportation is providing a viable option for individuals, and in particular it can be used to show for whom it is an option, which is often a key part of a public transit agency's goals. By showing how strong of an option public transportation is by neighborhoods or demographic group, agencies can be assured that they are providing public transportation where they believe it is needed most.

5 Conclusion

This project began with the naïve goal of developing a metric that would fully encapsulate the performance of a transit agency by looking at how well it could carry residents to jobs. It seemed like a perfect way to introduce an objective measure that could be the basis for a data-driven decision-making process within transit agencies that can sometimes seem to be driven by instincts, political pressures, and special interests. As the research progressed, it became clear that accessibility metrics did indeed work very well, but they were not a panacea that would direct all transit agencies inexorably toward efficient routing and optimized service allocation. The aggregated metrics that incorporate the full 24-hour service span offer great promise as a measure of how effective a service change will be. They even offer the opportunity for transit agencies to develop a small number of selected performance measures that are tailored to the values and goals of the organization.

This accessibility analysis was not easy, but the fact that it could all be done with an off-the-shelf laptop and free software represents a great advance in making this type of analysis available to transit agencies all over the world. This thesis showed how gaps in transit service can be identified by checking how greatly access to jobs during the peak varied from the average. This thesis only scratched the surface of what can be done in the planning profession with these tools as more sophisticated statistical analysis can be used to identify gaps in transit service and areas where service levels are disproportionate to demand. It is also possible to overcome many of the limitations of the methodology in this thesis to provide a more refined, granular analysis that minimizes the impact of travel time thresholds or oversized geographies.

Finally, as the body of research grows in this field, it may become possible to evaluate the return on investment that is offered by different transit service scenarios and the extent to which access to jobs can predict ridership. Going a step further the accessibility analysis can be used as a tool to clarify how decision makers think about transit. It would be possible to devise an accessibility metric that weights access to jobs for low-income individuals more heavily than a wealthy individual if the agency views serving low-income residents as a priority. One of the most attractive things about using accessibility metrics is that they are infinitely flexible and can be tailored to suit the needs of the transit agency, policy maker, or researcher. The challenge is balancing the high levels of sophistication that are possible with weights and gravity-based models with the need for a transparent and legible analysis.

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Appendix A – R Script

```
#The working directory should be set to a folder containing the Open Trip Planner output
setwd("~/Documents/Data Output/9-15-2015")

#Create a vector listing the names of all the csv files exported from OTP
file_names = dir()

#Create a very large dataframe, combining all of the csv files exported from OTP.
#This took about 20 minutes to process.
otpdata091515 <- do.call(rbind,lapply(file_names,read.csv))

#Import 2014 Census LED Data
leddata2014 <- read.csv("~/Documents/Data Input/Points/OP-JP-SBP BG Data.csv")

#Merge Open trip planner output with census jobs data
#Required more than 8 hours
alldata091515 <- merge(otpdata091515, leddata2014, by.y = "GEOID", by.x = "destination")

#Create a new table with only the rows which have a travel time of under 1,800 seconds (30 minutes)
#Less than 2 hours
alldata091515U30 = alldata091515[which(alldata091515$travel_time<1800),]

#Install "dplyer" package
library("dplyr", lib.loc="/Library/Frameworks/R.framework/Versions/3.3/Resources/library")

#Create a new table identical to previous, but grouped by trip "origin"
DataGroup = group_by(alldata091515U30, origin)

#Create a new table based on the sum of the number of jobs for which the travel time is under 30
minutes
Final = summarise(DataGroup, Jobs=sum(Sum.of.Jobs, na.rm = TRUE))
Final = mutate(Final, Jobs = Jobs/144)
```

Appendix B – Python Script

This script was downloaded from GitHub and slightly modified by the author to assist with usage of OpenTripPlanner software (Pereira, 2016)

```
#!/usr/bin/jython

from org.opentripplanner.scripting.api import OtpsEntryPoint

# Instantiate an OtpsEntryPoint

otp = OtpsEntryPoint.fromArgs(['--graphs', '.',

                             '--router', 'portland'])

# Start timing the code

import time

start_time = time.time()

# Get the default router

router = otp.getRouter('portland')

# Read Points of Destination - The file points.csv contains the columns GEOID, X and Y.

points = otp.loadCSVPopulation('points.csv', 'Y', 'X')

dests = otp.loadCSVPopulation('points.csv', 'Y', 'X')

for h in range(0, 24):      # Loop every hour between 7h and 13h

  for m in range(0,60,10):  # Loop every 10 minutes

    # Create a default request for a given time

    req = otp.createRequest()

    req.setDateTime(2016, 9, 1, h, m, 00)  # set departure time

    req.setMaxTimeSec(7200)               # set a limit to maximum travel time (seconds)

    req.setModes('WALK,BUS,RAIL')         # define transport mode
```

```
    # Create a CSV output

    matrixCsv = otp.createCSVOutput()

    matrixCsv.setHeader([ 'year','depart_time', 'origin', 'destination', 'walk_distance', 'travel_time' ])

    # Start Loop

    for origin in points:

      print "Processing origin: ", str(h)+"-"+str(m)," ", origin

      req.setOrigin(origin)

      spt = router.plan(req)

      if spt is None: continue

      # Evaluate the SPT for all points

      result = spt.eval(dests)

      # Add a new row of result in the CSV output

      for r in result:

        matrixCsv.addRow([ 2015, str(h) + ":" + str(m) + ":00", origin.getStringData('GEOID'),
r.getIndividual().getStringData('GEOID'), r.getWalkDistance() , r.getTime()])

    # Save the result

      matrixCsv.save('traveltime_matrix_'+ str(h)+"-"+str(m) + '.csv')

# Stop timing the code

print("Elapsed time was %g seconds" % (time.time() - start_time))
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Vita

Kevin G. Harrison began taking classes towards the Master's of Urban and Regional Planning degree at the University of New Orleans in 2011. During this period he has worked as a transportation planning consultant in New Orleans and has been active in the planning community. Kevin grew up in North Carolina and received his undergraduate education at St. Bonaventure University in Western New York. Kevin served in the United States Peace Corps in Panama and then worked in IT and construction management in North Carolina and Washington, DC respectively. Kevin aspires to continue his work in urban planning and help communities to provide convenient, healthy, sustainable, and affordable transportation options.