MEASURING THE UNMEASURABLE: A QUANTITATIVE APPROACH TO MEASURING ACCESSIBILITY

by

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TO MEASURING ACCESSIBILITY

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ABSTRACT

Accessibility has been a topic of research and conversation since the late 1950s. However, the ability to accurately measure accessibility rather than simply define it is becoming reality due to new software tools. This research will measure transportation accessibility with the help of the ArcGIS add-in, Sugar Access. Auto, transit, bike, and pedestrian networks’ accessibility will be quantitatively measured and evaluated. In addition to the study of current transportation networks, new bike and pedestrian networks were developed to add a level of comfort factor to the overall accessibility score. A level of comfort analysis in pedestrian and bike scenarios helps to create more realistic measures of accessibility.
Chapter 1

INTRODUCTION

“Accessibility refers to people’s overall ability to reach desired services and activities (together called opportunities) …” (Litman, 2003). Litman (2003) explained that several factors can affect accessibility: mobility (the ease of physical movement), proximity, transportation system connectivity, affordability, convince, and social acceptability. The study of accessibility in geography and related disciplines has a history dating back to Ernst Geog Ravenstein’s work over a century ago. In the late 1940s to the 1960s, scholars such as Zipf, Stewart, Wamtz, and Wilson theorized about the way individuals and aggregates of individuals respond to the constraints of cost, time, and effort (Couclelis & Getis, 2000). The ability to quantitatively measure accessibility proves to be a difficult and complex problem to solve. The multitude of origins, destinations, and routes creates the need for a multi-faceted approach to quantitatively define accessibility. In recent years, GIS models have assisted in scaling this problem down to become measurable.

This research uses a new ArcGIS application, Sugar Access, to analyze accessibility measures in the state of Delaware. Not only is this tool utilized to understand auto, transit, bike, and pedestrian accessibility, but its strengths and weaknesses are also tested and evaluated. In addition, the possible use cases of Sugar Access are discussed and analyzed. This research uses past research to understand problems and issues with accessibility measures and helps to further solve and confirm measures.
This research will start with a literature review of what accessibility is, how it has been measured, and why gravity models are important when understanding human nature. It will then explore the capabilities of auto and transit accessibility and describe possible uses of Sugar Access and its results. Whether or not a road is bike-able (comfortable to bike on) and how road and traffic attributes affect comfort levels will be discussed. This idea is further explored with pedestrian accessibility and the same difference, whether a road is walk-able, or comfortable to be walked on. Accessibility, while once a qualitative measurement, has become easier to quantitatively measure and discuss, leading to even more development and confirmation of the measures.
Chapter 2

LITERATURE REVIEW

This literature review serves to understand past work that has been completed regarding measuring transportation accessibility as well as evaluating gravity models. While there has been thorough research in the concept of accessibility, the term accessibility itself can be used in many different disciplines. It was important to limit this literature review to the study of motorized and non-motorized transportation accessibility. The major objective of this research is to understand how transportation accessibility has been studied in the past and how new tools in GIS have allowed for greater research to be done. This paper will take the past research as building blocks to understand measuring accessibility and then create new models to quantitatively measure accessibility.

2.1 Accessibility

As stated previously, the word “accessibility” can be used in many different disciplines. There is technology, housing, web and music accessibility, as well as the accessibility of government statistics and many other examples. The definitions of accessibility most critical to this research are: capable of being reached (a spatial definition); capable of being used or seen (a use definition); and easily used or accessed by people with disabilities (a user definition). Not only does the definition accessibility range across a multitude of disciplines, Guers and van Wee (2004) agree that “[transportation] accessibility is defined and operationalized in several ways, and
thus has taken on a variety of meanings [including] ‘the potential of opportunities for interaction’, ‘the ease with which any land-use activity can be reached from a location using a particular transport system’, ‘the freedom of individuals to decide whether or not to participate in different activities’ and ‘the benefits provided by a transportation/land-use system.’” Not only is the term accessibility interchangeable throughout many subjects, one can also consider relative accessibility between “two [different] people in the same place may evaluate their accessibility differently, as wants and tastes vary” (Handy, 1997). The multitude of definitions of accessibility contributes to the struggle of having a singular method to quantitatively measure accessibility.

Transportation accessibility is the ability to first reach a mode of transportation to then reach jobs, schools, food, healthcare, shopping, and other destinations. In 2004, Guers and van Wee described four components for accessibility: land use, transportation, temporal, and individual. The land use component describes the number of opportunities (or destinations) available, and the demand for these specific opportunities. An urban, suburban, or rural neighborhood changes how accessible its residents are to goods, jobs, or hospitals. Not only are the amount and the type of goods different given the different neighborhoods, the access to different modes of transportation greatly differs. The transportation component encompasses the amount of time, cost, and effort needed for different transportation modes in order to travel from an origin to a destination. A city may offer a multitude of public as well as private transportation, while a rural neighborhood will most likely have its residents dependent on cars. Socioeconomic factors also affect the transportation component because the difference between a person’s ability to take public or private
transportation is directly correlated to their access to a destination. The different modes of transportation analyzed in this paper are walking, biking, public transport, and private transport (vehicles) as well as a combination of these modes.

Congestion can vary at different hours of the day therefore AM Peak, Midday Peak, PM Peak, and daily average periods were examined. Public transportation timetable schedules were also used to help determine the availability of routes at different hours of the day. These describe the temporal component, or the availability of services that Guers and van Wee (2004) describe.

The individual component amasses all the needs of an individual to reach a certain destination. This entails the needs, ability, and opportunities of an individual. An individual’s age, economic status, abilities, and opportunities play a large part in personal accessibility. A person’s age can directly lead them to taking different modes of transportation. In addition, the socioeconomic status of a person can also decide the mode of transportation due to travel budgets and opportunity to borrow or buy a car. The abilities of person also are a factor in his or her choice of transportation. An individual that does not have the ability to walk to a bus stop may limit their use of public transportation and therefore they must rely on paratransit services or rides from family members. Finally, not only do the opportunities of jobs available matter to accessibility, but the ability for an individual to obtain that job is what is most important. This would mean that all jobs that need college degrees would only be “available” or reachable to college graduates. This idea can also correlate to different destinations available. Lower socioeconomic people, we can assume, would shop at different stores that higher socioeconomic people. While the destination is not necessarily unreachable, the average amount of trips to the stores would vary greatly
between the two socioeconomic classes, thus changing the measure of accessibility. Overall, the quantitative measure of accessibility has many factors that can make the outcome hard to reach. However with the help of new technology, many of these factors have become quantifiable.

2.2 Measurement of Accessibility

The quantitative measurement of accessibility has a history of different methods and ideals that have been long discussed. Hansen (1959) defined measuring accessibility as “the potential of opportunities for interaction.” He was careful to point out that this new definition differs from the previous one in that it is a “measure of the intensity of the possibility of interaction rather than just a measure of the ease of interaction.” However, in 1997, Handy and Niemeier concluded that “there is no best approach for [measuring] accessibility because different situations and purposes demand different approaches.”

These two distinctions are important when it comes to a measure of accessibility. It can be argued that the measure of accessibility could only be the ease of interaction. Krizek (2010) argued that “people may strongly prefer to get to some places that are difficult to access.” For example, simply because a grocery store is the closest by mileage, it does not mean that it will be the one used. Rather, it has the greatest possibility of being selected. But due to human nature, the products sold as well as product prices determine if someone will choose a grocery store that, by mileage, is farther away. If accessibility were to be measured only by ease of access, this would technically be choosing a store that had a measure of lower accessibility. To create a realistic measure of accessibility, human nature needs to be accounted for.
As discussed, the measure of accessibility has many factors to take into account. Handy (1997) added to the measurement stated that accessibility is thus determined both by patterns of land use and by the nature of the transportation system. This would show that not only are the origins, destinations, and people significant factors, but the modes of transportation and the quality of routes also contribute to the measure.

In 1990, the Americans with Disabilities Act (ADA) became law. This act “was a civil rights law that prohibits discrimination against individuals with disabilities in all areas of public life, including jobs, schools, transportation and all public and private places that are open to the general public” (Adata.org, 2017). This act had many impacts on public transportation across the nation. Not only did transportation networks such as sidewalks need evaluating, bus stops and ramps also had to brought up to code. For ADA accessibility standards, not only was the presence of a sidewalk needed, but as Handy (1997) states, “the condition of the road or sidewalk would also need to be taken into consideration.” This research and its discussion of future work take the conditions of the roads and sidewalks into account in order to provide more accurate measurements of accessibility.

2.3 Gravity Models

Gravity models are a widely used form of spatial interaction models. In 1955, Allen Voorhees was the first to apply an adaption of Reilly’s Law of Gravitation to transportation travel patterns when studying shopping habits and patterns. His study forecasted trips based on auto travel time as a distance factor and the retail floor area. In Figure 2.1, the frequency of trips to shopping centers does decrease as the distance from the origin increases.
While accessibility encompasses the ease of interaction, the act of the interaction can be quantified as well. According to Kingsley E. Haynes and A. Stewart Fotheringham (1984), gravity models are “the mathematical formulations that are used to analyze and forecast spatial interaction patterns.” Gravity models help to describe the relative importance of a location. Economists, city planners, transportation analysts and urban social theorists all use gravity models to help determine the attractiveness of a location or an opportunity. Krizek (2010) explains that the measure “considers destinations of interest along with the costs of travel (by any mode), and it incorporates more complexity into the calculation of ‘opportunities’.” A gravity model is most notably a function of distance between the origins and destinations and the opportunities available.

The gravity-based model in transportation has been developed over time. In 1959, Hansen was the first to apply gravity models to accessibility. He formulated it as:
\[ A_i = \sum_{j=1}^{n} S_j f(d_{ij}) \]

(2.1)

Where \( A_i \) is the job accessibility for zone \( i \), \( S_j \) is the number of jobs available in zone \( j \), \( n \) represents the total number of employment zones, \( d_{ij} \) is the travel impedance (distance of time) for a trip between \( i \) and \( j \), and \( f(d_{ij}) \) is a distance decay function to explain how the attractiveness changes based on distance. In 1988, Shen believed that the gravity model did not capture how demand also played a role in accessibility. He created a new model that added the demand potential in zone \( j \), \( D_j \):

\[ A_i = \sum_{j=1}^{n} \frac{S_j f(d_{ij})}{D_j} \]

(2.2)

Where:

\[ D_j = \sum_{k=1}^{m} P_k f(d_{kj}) \]

(2.2)

\( P_k \) is the number of workers living in zone \( k \), \( m \) is the total number of zones, and \( d_{kj} \) is the travel impedance between zone \( k \) and zone \( j \). Overall, gravity models have been used extensively in the transportation field to help quantify a location’s level of attractiveness to a person. Adding in the demand function helps to separate not only the level of attractiveness, but the possibility of a person needing to travel to a certain location. The addition of the demand potential model is greatly used throughout this research. In order to accurately measure accessibility, the distance, demand, and number of destinations all are necessary factors.
Chapter 3
METHODOLOGY AND RESULTS

This chapter will cover the methods used in this research to evaluate and create accessibility measurements. The goal of this research is to assess the value of transit routes as well as develop pedestrian and bicycle networks that can be evaluated using Citilabs’ Sugar Access, an ArcGIS add-in, to better determine accessibility. Data has been used to analyze accessibility throughout municipalities in Delaware.

3.1 Background

Measuring accessibility in ESRI’s ArcGIS has primarily been done through the Network Analyst tool. Even though this tool provides reliable information in terms of understanding accessibility from one origin to one destination, Network Analyst can be a tedious tool developing relationships between multiple origins and destinations. Network Analyst measures can the shortest route between two points and measure the number of residences within a specified radius. A weakness of this tool is that it cannot consider multiple origins and destinations when conducting an analysis. In addition, Network Analyst only conducts single mode trip analysis. For example, a person can travel from their home to a specific destination not needing another mode of transportation. However, for a public transit measure, the ability to walk to a bus stop is as important as the destinations a person can reach while riding the bus. Sugar Access has transformed the way accessibility can be measured in that it has the ability
to factor in multiple origins to multiple destinations with multimodal analysis on many different transportation networks.

3.2 **Sugar Access**

This research primarily used the platform Sugar Access to measure and evaluate accessibility. Sugar Access provides a quantitative measure of accessibility which is defined on a scale from 0-100. This scale allows the direct comparison of different locations’ accessibility. Sugar Access has three main differences to ESRI’s Network Analyst. Sugar Access provides accessibility scores for each geographic zone under analysis. These geographic zones can be communities, census blocks, census groups, or even individual tax parcels. This platform is also proficient as a scenario planner. Sugar Access can input two different network scenarios at once and output the change in accessibility that occurs. For example, this scenario analysis could include bike path designs.

Sugar Access allows for three different types of analyses: travel time, destination summation, and accessibility score. A travel time analysis uses a geographic zone layer and a transportation network layer to calculate the travel time from each zone to the nearest point or points of interest. The output of this function is essentially a heat map of the zones with each one’s minimum travel time to the destination calculated. The minimum walk time to the nearest bus stop in Newark, DE is an example of this analysis below in Figure 3.1. This analysis helps locate certain areas which are lacking access to different destinations.
The second main analysis in Sugar Access is a destination summation. Much like the travel time analysis, the destination summation takes into account a geographic zone layer and a transportation network layer. This analysis’ output is a map with an attribute table that displays the number of destinations that are within a certain radius (either time or distance) of each zone on a particular transportation network or networks. An example of this analysis is in Figure 3.2 below, the number of bus stops with in a 15-minute walk radius in Newark, DE. This analysis is helpful in understanding accessibility as it relates to quantity of destinations available.
The final type of analysis that can be completed with Sugar Access is an access score analysis. This function can calculate access scores for work (number of jobs), access scores for non-work (grocery stores, hospitals, schools), and as open access scores. The access score uses a decay function to determine a score from 1-100 of relative access for each inputted zone. These three analysis methods were used extensively in this research to analyze and develop new networks.

It is important to note that this research was done with the focus to analyze and accept the outputs from Sugar Access as well as develop new networks with ArcGis to fill in gaps of the platform. In the next few sections, the strengths and weaknesses of Sugar Access will be discussed to understand the development of focus areas that were created and then analyzed.
3.3 Data

This research is heavily dependent on data files in ArcGIS. When acquiring the Sugar Access license, Citilabs developed and distributed multiple data files that are used in this research. The files that come with the Sugar Access platform are: a roadway network, a transit network, a point of interest layer, a census block layer, and a census block group layer. The files included the entire state of Delaware as well as a fifteen-mile buffer. The transit network that was used was built from the GTFS or the General Transit Speed Specification for both the SEPTA and DART systems including travel times and routes. The roadway network was developed from what is now known as HERE, formally NAVTEQ. The census data layers were developed from the 2010 census and LODES (Longitudinal Employee Household Dynamics) information. In each of the census files are multiple attributes, from how many households are without cars to the number of children in each census block or block group. The last file received from Citilabs for this research is the point of interest (POI) layer. This is a point layer in GIS that was also developed from HERE data. Any and all points of interest in Delaware and the fifteen-mile buffer were accounted for. Some specific examples of what was included in this layer are: pharmacies, convenience stores, post offices, bars or pubs, and even ice-skating rinks. This data allowed the analysis of accessibility to food deserts, healthcare accessibility, and more.

Because the HERE data is primarily used for vehicle routing to points of interest, information did not exist within the dataset to show walkability and bike-ability along the road network. The data that was provided consider all roads, besides limited access highways and interstates to be both walkable and bike-able. However, it is unlikely that a pedestrian would choose to walk along a high speed, high volume
road when no sidewalks are provided. And cyclists would similarly be unlikely to bike along roads that do not have adequate cycling facilities, such as bike lanes.

To create better bicycle and pedestrian networks, data was used from the Delaware Department of Transportation. The state’s sidewalk inventory and bike path inventory were used in this research to develop networks. DelDOT had also developed a bicycle layer which includes a measure called level of comfort along each link that ranged from 1-4. More information can be found in Section 3.6 about the development of this bicycle network. It was important in the pedestrian analysis of this research to understand the difference in accessibility at a parcel level analysis, rather than census block level because census blocks are large geographic zones and would not provide the detail needed for this analysis. A parcel layer was received from New Castle County then used in the Sugar platform.

While the data files, both collected from outside sources and received with the Sugar Access license, were large data sets that drove this research, there was also accepted data that can be run through the Sugar Access framework. When running any open accessibility models, there is an option to use a decay function. Figure 3.3 illustrates the decay functions for the four different modes of transportation: auto, transit, walk, and bike with transit having the least exponential curve. It can be assumed and accepted that people will commute more comfortably for a longer period of time on transit than the other modes of transportation. In comparison, walking has the most exponential curve because most researchers have accepted that people will only walk comfortably, and without looking for other means of transportation, for a quarter of a mile to a bus stop and a half of a mile to a train station.
To understand issues and gaps in the data, control test trials were done to understand how the Sugar Access platform performs at accomplishing analyses. Any singular analysis done in the Sugar Access platform will be considered a ‘trial’. One drawback of Sugar Access is that it can only evaluate 32,000 polygons at a time. For reference, the State of Delaware with a 15-mile buffer has 74,556 census blocks. The trials shown in Figures 3.5 and 3.6 ignored the grocery stores that are right below the county line. Without having a proper buffer, the walking accessibility in the south part of the county border would not be accounted for. Moving forward buffers will be implemented when running trials when cutting GIS layers. One of the first issues that needed to be addressed when working with the Sugar Access platform was developing a correct buffer around the polygon layers when running each trial.
Figure 3.4: Walk and Bike Accessibility to Grocery Stores, New Castle County, DE

Figure 3.5: Non-Buffer Analysis Walk Accessibility to Grocery Stores in New Castle County, DE
3.4 Auto Analysis and Results in Sugar Access

The auto analyses that were done in Sugar Access showed accessibility to work, schools, and other destinations in the State of Delaware. The quality of the HERE road network data and point of interest data provide excellent analysis of accessibility to jobs or points of interest by autos. Below in the left pane of Figure 3.6, the accessibility to jobs by car is displayed and shows the difference between an accessibility analysis and the number of jobs accessible by auto in New Castle County.

Figure 3.6: Auto Access to Jobs Scores compared to Amount of Jobs Accessible by Auto in New Castle County, DE

Another trial that was run in New Castle County was the accessibility to healthcare facilities, as included in the Sugar Access data and can be seen below in Figure 3.7. Again, these results are what could be expected as the healthcare options are much greater in the northern part of the state and closer to the city of Wilmington, DE.
Figure 3.7: Accessibility to Health in New Castle County, DE

Figure 3.8: Access to Education in New Castle County, DE
The accessibility to education by auto was also measured and shown in Figure 3.8. Again, these results show that the largest access to education in New Castle County is closest to the area where the largest college is located, University of Delaware. The auto accessibility trials in Sugar Access continued to give results which were expected. Overall, auto accessibility and creating more accurate measures was not the focus of this research because it was accepted that Sugar Access does this in a way that is better than most applications available.

3.5 Transit Analysis and Results in Sugar Access

The next set of analyses done related to transit accessibility. A trial was run in Kent County, DE, a county with an urban/agricultural mix. One trial was run to analyze the number of low-income jobs that are accessible from the census tracts in Kent County, shown in Figure 3.9. If the assumption is made that people taking transit to low income jobs do not have access to a car, then the comparison of these was needed. This comparison concluded that while certain areas of the county had favorable access to Delaware’s transit system, most did not. People would have to travel multiple miles to be in a census block area that had a larger access to lower income jobs. This kind of analysis is important to help answer questions that may have not been able to be measured before.
This Kent Country trial led to the next phase of this research: how valuable are specific transit lines? What makes them worth the money to operate and how can each line, individually, be assessed? To understand this, multiple bus lines were removed from the transit network one at a time and then evaluated. State and Local DOTs could
use this analysis to consistently evaluate each bus line and the accessibility it offers to its riders. The results of this analysis are expanded on in Chapter 5.

A bus line along Kirkwood Highway was removed from the transit network in Sugar Access and the change in results was analyzed. This bus line is travels from the University of Delaware along Kirkwood Highway to the city of Wilmington, DE. Along the route are housing developments, as well as many businesses. This analysis proves why this specific bus line is imperative to residents in this area to access jobs. However, analysis of smaller bus lines could end up showing that they are not as effective or imperative for residents to get to jobs. This analysis could help to save costs for bus operations or prove why bus lines could be merged for the greater utilization of resources.

Figures 3.11, 3.12, and 3.13 show the removal of the bus lines along Kirkwood Highway. In certain census blocks there was a significant shift in accessibility to jobs. In addition to the analysis done for transit to all jobs, an analysis of transit to low income jobs was also taken into account. A bus line could be more important to a person that is travelling by transit to a low-income job in order to save money. This rider would be classified as a “need-based rider” compared to a “choice rider.” For these need-based riders in certain census blocks, a loss of access 9000 jobs were recorded. Again, Kirkwood Highway is a major route getting into the City of Wilmington or the University of Delaware. This analysis shows an extreme case of bus line removal. In future work, this concept to measure each bus line in a state and optimize bus lines is further discussed.
Figure 3.11: Transit Access Scores in New Castle County

Figure 3.12: Access Score Change to All Jobs in New Castle County with the Removal of Kirkwood Highway Bus Lines
Overall, the ability to assess transit accessibility was found to be rather easy. This data and analyses can be used in many different ways, including the scoring of bus routes to understanding the accessibility certain census blocks have to different destinations on the transit network. However, the highway network has many issues when measuring pedestrian and bicycle accessibility. In the next sections, non-motorized accessibility will be discussed and analyzed.

3.6 Bike-ability Analysis and Results in Sugar Access

Bike-ability is a difficult mode of transportation to measure. While Sugar Access has the capability to measure bike-ability, this is still measured on the entire highway network. Due to the varying skill levels of cyclists, bike-ability must account for attributes like presence of bike lanes, speed of adjacent traffic, etc. The concept of bike level of traffic stress (LTS) was formalized by the Mineta Transportation Institute (Citilabs, 2017). Roadways are given an LTS score based on the number of lanes,
speed limit, functional class, and the presence of bicycle facilities (where data is available).

The Delaware Department of Transportation created a GIS bike network that factored in the same levels of traffic stress (LTS) attributes from the research done by the Mineta Transportation Institute in 2012 and can be seen below in Figure 3.14. In Table 3.1, the condensed descriptions of each level of traffic stress by Peter G. Furth is shown. This level of traffic stress network had values for roads in Delaware and each link had a score of 1-4 and can be seen in Table 3.14. Because the highway network that is used in Sugar also has a 15-mile buffer, any road that did not have a value was given no score. Therefore this analysis focused on smaller areas inside state boundaries. The original concept for the bike network was to use the bike-ability shape file and turn it into a network that could be run through the Sugar Access platform.

To account for bike-ability, four different networks were built. It can be assumed that a cyclist that will travel on a road that has a level of traffic stress of four (the most intense) will also feel comfortable on anything less than a four. The four networks built were: LTS 1-4, LTS 1-3, LTS 1-2, and LTS 1. These networks were to be implemented in the same way the sidewalks were, as discussed in the next section. The main goal of developing this new bike network was to create a more logical movement of bikes across a network to allow for the most accurate measure of accessibility. It was about creating distinctions between the ideas that while a road may be technically bike-able, the accessibility scores would exclude roadway links if that link was not comfortable to the cyclist. Unfortunately, the attempts to develop these new networks did not give coherent results.
<table>
<thead>
<tr>
<th>Bicycle Level of Traffic Stress</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strong separation from all except low speed, low volume traffic. Simple crossings. Suitable for children</td>
</tr>
<tr>
<td>2</td>
<td>Except in low speed / low volume traffic situations, cyclists have their own place to ride that keeps them from having to interact with traffic except at formal crossings. Physical separation from higher speed and multilane traffic. Crossings that are easy for an adult to negotiate.</td>
</tr>
<tr>
<td>3</td>
<td>Involves interaction with moderate speed or multilane traffic, or close proximity to higher speed traffic. A level of traffic stress acceptable to those classified as “enthused and confident.”</td>
</tr>
<tr>
<td>4</td>
<td>Involves interaction with higher speed traffic or close proximity to high speed traffic. A level of stress acceptable only to those classified as “strong and fearless”</td>
</tr>
</tbody>
</table>
While creating a brand-new network to run through the Sugar Access platform failed, there was another way to measure bike accessibility. Look-up tables were created to update link speeds based on the level of traffic stress value. It is important to note that this method does leave room for error, as each link is two directional. However, it would likely be a rare occurrence where conditions for cycling existed on one side of a link and not on the other.

The scenarios to be tested were created and the same ideology of cycling comfort was used. In Table 3.2, the four look-up table scenarios are described. A bike-ability look-up table was created for each scenario and can be seen below in Table 3.3. The values of each LOS correspond with the change in link utility factors. In Table 3.4, the utility factors are given for a bicyclist travelling at 9.0 mph. As the assumed
speed of a bicyclist changes, so does the mile equivalent. As with the pedestrian network in the platform, the bicycle network was also treated as a decay function per link and then a decay function over the entire model. For example, a value of 10 in the look up table would reduce a link to 10% of its original speed, therefore a 10 mph link will act as a 1 mph link. This will cause the platform to either use the route at a much slower speed or select a faster and more comfortable route. Because only the LTS values were available for the state of Delaware, any road without a value received a utility factor of 10%.

Table 3.2: Scenario Descriptions of Level of Traffic Stress Trials

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A beginner cyclist that will only be comfortable biking on a road that has a level of traffic stress value of 1</td>
</tr>
<tr>
<td>2</td>
<td>An intermediate cyclist that will only be comfortable biking on roads that have a level of traffic stress values of 1 or 2</td>
</tr>
<tr>
<td>3</td>
<td>A risk-taking cyclist that will be comfortable biking on a road that have a level of traffic stress of 1, 2, or 3</td>
</tr>
<tr>
<td>4</td>
<td>A fearless cyclist that will be comfortable biking on roads that have any traffic stress values</td>
</tr>
</tbody>
</table>
Table 3.3: BikeLOS Look Up Table Values

<table>
<thead>
<tr>
<th>LOS</th>
<th>Scenario</th>
<th>1 (80%)</th>
<th>2 (80%)</th>
<th>3 (80%)</th>
<th>4 (80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 (10%)</td>
<td>5 (80%)</td>
<td>5 (80%)</td>
<td>5 (80%)</td>
<td>5 (80%)</td>
</tr>
<tr>
<td>2</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>5 (80%)</td>
<td>5 (80%)</td>
<td>5 (80%)</td>
</tr>
<tr>
<td>3</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>5 (80%)</td>
<td>5 (80%)</td>
</tr>
<tr>
<td>4</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>5 (80%)</td>
</tr>
<tr>
<td>All Other</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
<td>1 (10%)</td>
</tr>
</tbody>
</table>

Table 3.4: Bicyclist Level of Service Utility Facts (Citilabs, 2017)

<table>
<thead>
<tr>
<th>Bike Level of Service</th>
<th>LOS Level</th>
<th>Utility Factor</th>
<th>Mile Equivalent (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>100%</td>
<td>150%</td>
<td>4.4</td>
</tr>
<tr>
<td>9</td>
<td>130%</td>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td>8</td>
<td>120%</td>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>7</td>
<td>110%</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>100%</td>
<td></td>
<td>6.6</td>
</tr>
<tr>
<td>5</td>
<td>80%</td>
<td></td>
<td>8.2</td>
</tr>
<tr>
<td>4</td>
<td>60%</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>40%</td>
<td></td>
<td>16.5</td>
</tr>
<tr>
<td>2</td>
<td>20%</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>1</td>
<td>10%</td>
<td></td>
<td>65.9</td>
</tr>
</tbody>
</table>

The first trials completed with the LTS look-up tables were non-work, accessibility to all POI trials. Each trial had 5 scenarios, a control scenario that took no level of traffic stress values into account and the four bike-ability comfort levels. The
results of these trials can be seen below in Figure 3.15. While the results were as expected, the results also highlight just how big of a difference accessibility is for cyclists that would only be comfortable on a level one road. This data can be used to help find areas for improvement that will also make the biggest impact to cyclists’ accessibility to all POIs. Additional trials could be completed to more specific destinations; however this trial shows accessibility in a more general format that will help show the largest impact new bike paths, or road improvements will have as a whole.

The next trials that were completed explained the bike accessibility with level of comfort calculated to jobs in New Castle County. The results can be seen below in Figure 3.16. Some census blocks outside the city of Wilmington saw an increase in accessibility from 10,000 jobs to 20,000 jobs from scenario 1 to scenario 2. This would mean that a cyclist that is comfortable biking on a road that has a level of traffic stress of two has the potential to reach twice as many jobs by bike. This is an important and necessary analysis to prove that while a road may technically be bike-able, the level of comfort a cyclist has is more important when looking for routes to use regularly. Analyses like this can help find gaps in certain areas and then be re-run to show how a safer, more comfortable road can impact a cyclist.

Creating more roads that are comfortable for cyclists should be a common goal of DOTs nationwide. This could help people that normally use cars for everyday tasks, like grocery shopping or going to work, to feel more comfortable biking thus lowering auto congestion. In many metropolitan areas, this analysis could be done to measure the bike-ability of the road network and create a safer and more comfortable experience.
Figure 3.15: Bike Accessibility Trials to POIs With and Without LTS Look-Up Table
Figure 3.16: Bike Accessibility Trials to Jobs With and Without LTS Look-Up Table
3.7 Walkability Analysis and Results in Sugar Access

To better understand how analysis for pedestrian activity is conducted throughout the Sugar Access platform, trials were run with Citilab’s’ highway network and point of interest layers. Sugar Access uses the same highway network for autos as it does for pedestrians. There is an attribute that deems the segment of any road in the network “walkable” or not. The data set does not include the presence of sidewalks, crosswalks, shoulders, etc. which would all affect the walkability of a road. The default data set considers all roads to be walkable except for limited access highways and interstates.

In Figure 3.17, the issue with the highway network as a pedestrian network is shown. All road networks in this example are considered walkable by Sugar Access, however the sidewalk does end and has a large gap in it. The Sugar Access network would not take this into account.

Figure 3.17: Highway Network Compared to Sidewalk Layer

While this example is in a housing district and walking on the street may be safe, there are other areas where this is not the case. In addition, a roadway link is
considered, by the software, to be walkable in two directions. However, a road with a sidewalk on each side would have four different paths, two in each direction. This would mean that a network would only continue if a sidewalk is present. If this sidewalk never reached a crosswalk, the walkability would end. Therefore, walkability of an area should consider only sidewalk networks. This would allow for better handicapped accessibility to be measured as well. If a person in a wheelchair was in this neighborhood, this sidewalk ending would make this area not traversable.

The main reason this research focused primarily on pedestrian networks is because this analysis in Sugar Access is not as consistent with everyday life as the motorized analysis is. Just because a road is available, does not mean it should always be a part of the pedestrian network.

The sidewalk network used in this research was developed from the sidewalk inventory from DelDOT. More defining attributes were added to the attribute table to allow for the new network to run within the Sugar platform.

When running trials with the sidewalk network, tax parcel layers were used as the geographic zone to be analyzed. In comparison to census block analysis, tax parcel layers allowed for breaks in the network to be more specified to a point. The first trial was done to confirm that a parcel layer could be used as an analysis location. This parcel trial measured the accessibility to any grocery stores, convenience stores, and restaurants in the city of Newark, DE along the highway network. These three points of interest essentially test an accessibility to “food”. In Figure 3.18, the results are shown.

The second trial was an evaluation of the new sidewalk network. This trial was a destination summation of all bus stops that were within a 15-minute walk radius.
Bus stops were buffered by 5 meters in GIS and then merged with the polygon layer. An attribute of 1 was given to each bus stop to properly sum the amount of destinations that could be reached. Before this was attempted with the new network, a control run was done using the Sugar Access network as a walk analysis to the same bus stops using the parcel layer. This trial’s results in Figure 3.21 show how Sugar connects parcels to the network. The area studied was in a suburban area and not all sidewalks were connected. The results of the initial trial with the new sidewalk network are shown in the left pane in Figure 3.20. A specific area was chosen that was relatively close to different bus stop. This trial proved that it was the nodes’ location relative to the parcel which determined the ability to “get on” the network in order to reach the destination.

The next step was to use this specific area of tax parcels and add more links and nodes to the sidewalk network. The middle pane of Figure 3.19 shows the additional nodes that were added to this specific area. The results of this trial showed that this hypothesis was correct and that the network needed to have more nodes along the link. The parcels that were closer to the nodes were able, without any other changes, to reach more bus stops if nodes were relatively closer than before. A third scenario was then created to add even more nodes to the network, as can be seen in the third pane in Figure 3.19. The results of this trial, in the third pane of Figure 3.20, show that the parcels able to reach even more bus stops with the addition of more nodes in the sidewalk network. This trial further strengthened the argument that in order to create new networks and to have them react as expected, nodes will have to account for ways to get on a network. In Chapter 5, the creation of new sidewalk networks and possible future uses is expanded on.
Figure 3.18: Parcel to Food (Restaurant, Grocery, Convenience Store), Newark, DE

Figure 3.19: Node Additions to the Sidewalk Network

Figure 3.20: Walk Destination Summation Parcels with the Additional Nodes
Figure 3.21: Walk Destination Summation Parcels with Sugar Access Highway Network

These trials in pedestrian accessibility show the need for the development of better sidewalk networks in Sugar Access. The ability to safely cross a street in a crosswalk or walk along an arterial in comfort should be within the quantitative measure of accessibility. While human nature does not always account for people using sidewalks or crossing in crosswalks, the planning of a city’s pedestrian networks should.
Chapter 4

CONCLUSION

This research concludes that while accessibility is a difficult measure to create, the use of new tools, such as Sugar Access, allow greater certainty in the measure. Overall, auto and transit accessibility measures are reliable in the platform and can be used by many different agencies to answer questions and solve problems. The quantitative measure of accessibility can lend itself to help in project selection by DOTs. Another practical application that has been discussed is the measure of value of each line within a transit network. While an accessibility measure is not a tell-all measure for a certain census block or parcel, it is a tool that can be used in the decision making process of creating new roads or developing new transit lines to access that area.

However, this research magnifies the issues with bike and pedestrian accessibility. While a destination may be technically accessible, everyday users will not continue to bike or walk along roads with unsafe speed or lack of facilities. Bike-ability and walkability should be the driving forces of a network’s accessibility measure. In addition, there are further problems when using a centerline network to measure pedestrian accessibility. It is the city’s responsibility to create safe, pedestrian friendly networks and until sidewalk networks are used in Sugar Access, this accessibility measure is difficult to assess. As stated previously, the ability to safely walk to a bus stop is just as important as where the bus can take you. The walking
accessibility scores need to use specific sidewalk networks in order to show a safe, accessible route. This research shows simply the beginning of how sidewalk networks can be implemented in the Sugar Access platform. Once a sidewalk network’s data is verified, a multitude of pedestrian accessibility measures can be completed, with the most needed one being ADA accessibility. The ability to give a municipality quantitative data to describe the ADA accessibility of an area is valuable information and further progress in equity accessibility.

The next chapter will expand on some of the future opportunities that Sugar Access could provide. This tool has changed accessibility measures and can continue to provide valuable information when analyzing different transportation networks.
Chapter 5
FUTURE WORK

Many extensions of this research can be done to further study transportation accessibility. While this research primarily focused on creating pedestrian and bicycle networks that have more accurate measures of accessibility, auto and transit measures can also be further analyzed. There are many possible applications of the Sugar Access platform, from analyzing its results to further strengthening the accuracy of the trials. This section will lay out an extensive, however not exhaustive, list of possible further work.

One further area of study could be to continue to utilize different methods to analyze the results of the Sugar Access platform. Handy (1997) stated that “revealed behavior is shaped by the specific alternatives available…if a community does not have good pedestrian access, then residents will make few pedestrian trips, but this does not imply they would not make such trips if pedestrian access were better.” Further research could take this idea and study the outputs of accessibility using Sugar Access, before and after a change in a network, and then proceed to collect data in the community to confirm the analyses.

Another method to test the results of the trials would be to quantify and test different values when using look-up tables for different transportation networks. In this research, a look-up table was used to quantify different levels of comfort along bike routes. Another way a look up table could be used is to test accessibility during
less than ideal conditions, rain or snow, and create decay factors based on data and the impact these conditions would have to specific links in a network. This would lessen the speed along links in a network and allow for a more accurate measure of accessibility during adverse conditions.

One future application of Sugar Access could be to create a sidewalk network that could be run through the Sugar Access platform to quantitatively analyze and score ADA accessibility. This new network would need to include crosswalks and ADA accessible ramps. A network could be built in GIS that would theoretically turn on and off a link in the network based on whether an ADA compatible ramp is present. If a link was turned off, it would mean that it could not be used in the network and this would cause the analysis to select an ADA compliant path to get to destinations. One way to also measure this could be to use handicapped parking spots as the geographic zones that are being analyzed. This would produce the accessibility from each handicapped spot and show where there are breaks in the sidewalk network from these spots. Not only could ADA accessibility be analyzed, but additional ADA compliant ramps and sidewalks could be tested to understand the change of accessibility each brings to a network. This quantitative measure could lead to sidewalk projects being selected based on the amount of extended accessibility they provide.

In addition to the creation of new non-motorized accessibility measures, future work in the analysis of transit lines could be very valuable to transit agencies. Transit line prioritization and analysis within the Sugar Access platform would be an extension of the research completed in Section 3.5. For example, an agency like DART (Delaware Transit Corporation) that operates public bus transportation in the state of Delaware could use Sugar Access to understand, quantitatively, the value that
each bus line offers. While ridership data is already analyzed by DART, this is a new way to analyze any new or changes to bus lines. These measures could also help explain to the public why or why not a bus line is needed or whether one should be shortened or lengthened. As seen in this research, a larger more thorough analysis of the transit network can be completed to score each bus line. Because Sugar Access has the ability to choose different destinations, scores could be given based on a bus line’s ability to reach jobs, low-income jobs, hospitals, and even grocery stores. These scores could be weighted by importance and then added together to create a final score for each line. This analysis would be helpful in testing the transit network to look for underserved community members. In this analysis, it would be important to understand that while Sugar Access is a tool that can help make decisions, there should also be extensive work done to confirm the results. This future work would be of great value to help understand and quantify possible changes to a transit network and the access it brings to its riders.
REFERENCES


