Assessment of public transit and access to essential services and facilities in Huntsville, Alabama

Sachin Shivashankar

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ASSESSMENT OF PUBLIC TRANSIT AND ACCESS TO ESSENTIAL SERVICES AND FACILITIES IN HUNTSVILLE, ALABAMA

Sachin Shivashankar

A THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of Science in The Department of Civil and Environmental Engineering to The Graduate School of The University of Alabama in Huntsville

August 2023

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This study aims to investigate the accessibility of public transit within the City of Huntsville, Alabama, in Madison County. Accessibility, in this context, refers to the distance between the residents in a certain census tract to essential amenities such as hospitals, schools, parks, workplaces, and other necessary services using public transportation. Data were obtained from the US Census Bureau and the City of Huntsville’s Data Depot, focusing on aspects such as population socio-demographic attributes, and the distribution of essential amenities within the Huntsville city. Utilizing a range of Geographic Information System (GIS) methodologies and tools, including proximity analysis, random forest regression analysis, and optimized hot spot analysis, this thesis evaluates distance-based transit accessibility in comprehensive ways. Proximity analysis evaluates the distance from transit stops to places. Random forest regression analysis selects various key socio-demographic variables and evaluates the correlation among transit accessibility and such variables. Optimized hot spot analysis identifies areas with high and low transit accessibility. The combination of these methodologies and tools reveals various sociodemographic factors
correlating to transit accessibility. Further, this study suggests that public transit accessibility within Huntsville is heterogeneous spatially. South Huntsville, Harvest, Mountain Cove, and New Hope areas are among the regions lacking transit accessibility. This research provides insight from the perspective of distance-based transit accessibility for transit planning decisions and potentially helps the public transportation services in Huntsville become more comprehensive and equitable for the diverse needs of the residents.
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Chapter 1. Introduction

Accessibility, in general, refers to the ease with which citizens can transit between different locations within a city, such as homes, workplaces, essential services, and recreational sites. According to Miller (1999), the primary goal of any transportation service is not merely to extend its network but to enhance accessibility throughout the service area. His seminal work emphasizes that analyzing the service area can yield valuable insights into the accessibility index, thereby aiding in evaluating public transportation efficiency [15].

Public transportation accessibility has been the subject of numerous studies, focusing on factors such as transit timetables and the distance between stops and neighboring communities. As cities expand, reduced schedules and coverage can often lead to diminished public interest in public transportation, thereby bolstering the utilization of private vehicles. Park (2012) utilized Geographic Information Systems (GIS) in his research, employing descriptive and statistical analyses, as well as a road network-based distance measure, to bring a realistic perspective to public transportation accessibility [20].

In the context of Huntsville, Alabama, a developing center of innovation and technology, the Orbit shuttle service represents a vital facet of the city’s public transportation system. Evaluating its efficiency involves investigating as-
pects like Hot spot analysis, service reliability, and the accessibility of bus stops and stations. Moreover, considering the distribution and accessibility of essential resources like healthcare, education, grocery stores, and public safety forms an integral part of this evaluation.

The spatial analysis will help identify any possible coverage gaps within the city borders of Huntsville. This thesis aims to conduct an in-depth analysis of Huntsville’s transit service accessibility, thereby formulating pertinent recommendations. This research aims to enhance Huntsville’s public transit system by increasing accessibility, which could bolster public transportation usage.

Nicholls (2001) conducted his accessibility analysis using GIS by measuring the straight-line distance [18]. However, such an approach can lead to misinterpretation of travel distance, given the potential curved paths that transit users might use. Therefore, this research will utilize a Network analyst tool by creating the road network for a comprehensive distance-based analysis to provide a realistic portrayal of accessibility, facilitating further investigation in alignment with socioeconomic variables.

Exploring residents’ demographics helps identify potential barriers to transportation usage, such as means of transportation to work (MOT), poverty levels and different races. The study aims to devise targeted interventions to encourage other population groups to use public transit more extensively. Furthermore, this research will investigate the potential economic implications of increased accessibility to public transit in Huntsville.
The novelty of this thesis lies in its holistic approach to accessibility assessment. By examining factors like means of transportation to work, poverty levels, race, and access to essential services, this thesis aspires to assess the potential economic benefits of a more efficient and accessible public transportation system. According to Kwan and Weber (2003), accessibility should be perceived as the proximity of one location to other specified areas [12]. This study leverages this understanding to support the city’s long-term economic growth, informing future transportation planning.

In summary, this thesis aims to evaluate the transit system’s accessibility in Huntsville, bearing in mind the numerous daily life aspects that rely on adequate public transportation. The study will address various accessibility-related challenges, such as the sufficiency of service areas in meeting the diverse needs of the city’s population, the influence of socioeconomic factors on transit use, and the spatial distribution of frequent users. The findings from this comprehensive study are anticipated to culminate in recommendations to enhance Huntsville’s public transit system.
Chapter 2. Background

2.1 Overview

The background of this research paper delves into the multifaceted aspects of Huntsville City within Madison County, the methodology used, and the influencing variables concerning public transit accessibility. Huntsville, recognized for its rapid growth in the technology and innovation sectors, is witnessing an increasing need for a comprehensive public transit system. The city boasts diverse amenities such as restaurants, workplaces, housing, recreational spaces, and other vital facilities. However, the existing transit system’s accessibility to these services remains a question that this research aims to answer.

The city’s demographic fabric further adds to this complexity, with varying poverty levels, races and means of transportation to work (MOT) across its block groups. These factors, interwoven with the mode of transportation to work, can significantly influence the usage patterns of public transit systems. The present study seeks to demystify these relationships by examining Huntsville’s city limits based on block groups from the census data.

The primary objective of this thesis is to investigate the reality of public transportation in Huntsville and highlight the accessibility challenges its residents face. The work of Mesbah et al. (2012) serves as an essential reference here. They
utilized GIS to identify discrepancies between the actual and scheduled transit system, revealing the significance of spatial analysis in smoothing the data via inverse distance weighting [14]. A correlation analysis of public transport service areas with demographic attributes and essential amenities forms a pivotal part of this investigation. It aims to enrich our understanding of these issues and inform policy decisions to mitigate the impediments plaguing the transit service.

2.2 Study Area

The study area focuses on the Huntsville city metropolitan region within Madison County, Alabama. The analysis focuses on the 184 census block groups within the city, as determined by the 2021 census tract, accounting for the expanding urban area. Huntsville’s total population is 221,933 [25], with a diverse representation of races and income levels.

Public transit use is often minimal and confined to within the city borders, while a significant portion of the population relies on private automobiles for transportation. Examining existing transit usage trends and considering prospective transit network extensions are the main goals of this project. The findings will be used to guide future transit network planning. The figures representing the study area are shown in Figures 2.1 and 2.2.

2.3 Data Collection

The US Census Bureau website [25] and the City of Huntsville’s Data Depot [3] served as the two sources for the data utilized for this study. To better
understand the population distribution across different locations, the information obtained, which related to the Huntsville city metropolitan area, has been divided
into block groups. The data include demographics by race, employment location, poverty rates, educational attainment, and mode of transportation to work. For geographic analysis and grouping, this data were preprocessed into shapefiles and shown on a GIS map.

The study focused on how easily people could access important facilities such as restaurants, schools and universities, medical facilities, apartment buildings, grocery stores, and industrial parks. Shapefiles have been obtained from the City of Huntsville’s Data Depot to generate a network of roadways and a map of the city’s service area. The same source also yielded information on transit routes and stops. All the gathered information was transformed into shapefiles for preprocessing and was then created visually on the map. Each element was mapped to its corresponding latitude and longitude coordinates, and the names were mapped to corresponding block groups, to generate tables within shapefiles. This made it possible to show the data in a way that was both clear and easy to understand visually. The distribution of all the essential amenities and population within the various block groups in Huntsville, Alabama, can be determined through analyzing this data.

2.4 Service Area Analysis

The research examines the urban limits of Huntsville city and tries to evaluate the accessibility of essential facilities like parks, hospitals, restaurants, housing, places of work, and other services. The study further examined demographic data such as poverty, racial groups and means of transportation to and
from work. The city’s boundaries were analyzed based on census block groups to accurately depict each block groups and estimate the accessibility of public transit throughout the city.

The service area analysis in this study generated service areas using ArcGIS Pro shown in Figure 2.3, providing light on how easily accessible essential services are for Huntsville people. Each transit stop’s service area was specified as a 1000-meter radius that was divided into five sections at 200-meter intervals and shown with a graduated color scheme to provide thorough information about the accessibility of Huntsville city limits. Public transit service is essential and has a considerable shortfall in the city’s southwest and southeast, where industrial and residential complexes have experienced significant growth. The results show that modernizing bus routes and stations in the city’s outlying areas would be a huge step forward for the city’s transit system, providing an essential link for workers moving across the City, and easing highway congestion.

The study pinpointed parts of Huntsville close to essential services by establishing service areas. This data can be used to improve policy choices and marketing tactics to improve Huntsville’s public transportation system and expand accessibility to essential services.

In conclusion, the study offers insightful information about Huntsville, Alabama’s accessibility to necessities and availability of public transportation. These insights can be used by policymakers, transportation planners, and other stakeholders to address issues and enhance residents’ access to essential amenities.
Figure 2.3: Represents the service area coverage through transit in Huntsville city.

Figure 2.4: Spatial distribution of race across Huntsville city, Alabama.
2.5 Spatial Analysis

Figure 2.4 presents a spatial analysis of the distribution of different racial groups across the city of Huntsville. The dominant racial group in the city, represented by the purple spots, is “white alone”. The central region of the city, particularly in the Huntsville north and east Huntsville regions, illustrates a mixed racial composition with a significant presence of both “white alone” and “black or African American alone” households, represented by purple and green spots respectively. Furthermore, households from other races are also scattered throughout the city. Each spot symbolizes two households, aiding the visualization of racial heterogeneity in Huntsville.

The spatial distribution of different racial groups as portrayed in Figure 3 reveals the heterogeneity within Huntsville’s demography. The downtown area’s racial diversity calls for policies that embrace inclusivity and address the specific needs of different racial groups.

Figure 2.5 delves into the spatial patterns of commuting in Huntsville. It is evident that private vehicles like cars, trucks, or vans dominate the city’s commuting landscape. Each dot symbolizes two households, illustrating a substantial reliance on private transportation across the city. A small proportion of the population in the North Huntsville, Mill District and East Huntsville neighborhoods of the city center regions use public transit, while in the southwest region of Research Park, a small number of households show a preference for walking or
working from home. This might reflect the geographical differences in work and lifestyle patterns across the city.

The spatial distribution of transportation means to work in Figure 4 indicates a predominant reliance on private vehicles, underscoring the need for policy efforts to promote public transit commuting alternatives. The small proportion of public transit use in the downtown region hints at potential areas for improvement in public transportation services.

Figure 2.6 presents a spatial view of poverty distribution in Huntsville, depicting three main categories: households under 1.00 percent poverty level, households from 1.00 to 1.99 percent poverty level, and households with a poverty level above 2.00 percent. In the North Huntsville, Mill District, and East Huntsville regions, a mixed poverty profile is observed, with households in all three poverty levels...
categories present. On the other hand, the peripheral regions of the city predominantly exhibit higher poverty levels (above 2.00 percent). Furthermore, households experiencing poverty levels between 1.00 and 1.99 percent are found scattered throughout the city, although they represent a smaller proportion of the overall population.

The spatial analysis of Huntsville provides a clear understanding of the city’s socio-economic attributes like racial distribution, means of transportation (MOT) to work, and poverty exhibits spatial patterns across the city, underscoring the importance of location-based strategies in addressing the city’s diverse needs. The analysis reaffirms the need for integrating spatial considerations in urban planning, policymaking, and service provision to foster equitable urban development in Huntsville. Therefore, it is evident from the spatial analysis of a
variety of population variables that the city has extremely limited public trans-
portation coverage and that people tend to flee the area when a sizable section of
the population relies on private vehicles to get to work.

2.6 Data Analysis Approaches Explored in the Study

To foster an in-depth understanding of the studied geographical area, a
blend of data analysis tools is applied in the methodology.

2.6.1 Regression Analysis

Regression analysis is vital in examining dependencies between the ‘near
distance’ and other relevant attributes. Both linear and non-linear regression
models are employed to accommodate potential data patterns and ensure a com-
prehensive understanding of the interactions among variables.

2.6.1.1 Ordinary Least Square Method

Ordinary Least Squares (OLS) regression analysis provides a preliminary
understanding of the potential linear relationship between the near distance’ and
dependent variables. This technique, though simple, effectively estimates un-
known parameters in a linear regression model [17].

2.6.1.2 Random Forest Regression Analysis

Acknowledging the potential complexities in real-world data, a Random
Forest regression analysis is carried out, supplementing the OLS approach. Ran-
dom Forest proficiently manages complex relationships and interactions between variables [27] as a nonlinear method. The concept of feature importance serves as a crucial part of Random Forest regression analysis, offering insights into the attributes most relevant to predicting the “near distance.”

2.6.2 Proximity Analysis-Near Tool

The Near Tool in GIS software calculates the distances between features in a dataset. It aids in identifying the most accessible facilities from a given location or in creating maps displaying the proximity of different features [26].

2.6.3 Optimized Hot Spot Analysis

ArcGIS’s Optimized Hot Spot Analysis uncovers significant trends and patterns in spatial data. Its application ranges from identifying hot spots and detecting cluster outbreaks to analyze the patterns [2].

This research addresses the limitations of the system geographically by focusing on block groups within Huntsville. Such a granular analysis offers a more localized understanding of transit accessibility, providing insights that could inform enhancements to the public transit system on a block-by-block basis. It’s through quantifying accessibility levels and conducting a correlation analysis with the Random Forest regression analysis that the study seeks to fulfill its purpose.
2.7 Contribution of This Work

A comprehensive examination of public transportation accessibility in Huntsville, Alabama offers valuable insights into demographics, employment, and various amenities associated with public transit in the area [10][8][1]. The utilization of an array of data analysis techniques, including service area analysis, regression analysis, proximity analysis, optimized hot spot analysis, and spatial analysis [13][7], has facilitated a deep understanding of the existing transit situation.

The application of Ordinary Least Squares and Random Forest regression models [15][19][9] has illuminated complex dependencies and interactions, shedding light on the significant variables contributing to predicting ‘near distance’. This understanding can form the basis for strategic urban planning and transportation policy interventions.

The Proximity analysis-Near tool, has mapped distances between key city features [13], providing a spatial understanding of access points. The Optimized Hot Spot Analysis has been instrumental in identifying patterns in spatial data [7]. Spatial analysis further enhanced this understanding by revealing the connections between diverse spatial variables.

The study underscores the need for increased public transit accessibility, demonstrating its importance for community socioeconomic advancement [21][10]. The understanding gleaned from this study can guide the creation of tactical initiatives [5], leading to better public transit access, improved socioeconomic mobility, and elevated urban living standards for all Huntsville residents [8][1][16][19].
The ongoing expansion in all transportation sectors has led to a relatively slow pace of development in public transportation [4]. As a result, several studies have been conducted to foster innovation and growth in public transportation services [11]. These studies investigate the relationship between public transit accessibility and urban form, emphasizing the significance of an efficient public transit system in creating social equity, driving economic growth, and achieving transit objectives[10][8][1].

Further research into the travel patterns of different demographic groups [21], the factors influencing their mode of transport [5], and the distribution of necessary amenities in metropolitan areas [11], emphasizes the need for inclusive and equitable transportation policies and infrastructure. Evaluating the performance of Huntsville’s current public transit system, Orbit [7], has revealed the importance of transit stop accessibility, and service reliability.

Understanding the current state of the transit system, the accessibility to essential amenities, and the distribution of these services in Huntsville is critical due to the city’s growing need for public transportation alternatives [13][7]. Such understanding is vital in shaping policy decisions regarding transit network expansion and improvements, fostering more inclusive urban environments. The comprehensive literature review offers insightful guidance for future transportation planning in Huntsville.

However, in this thesis, the analysis is carried out by calculating the near distance of essential services from the nearest transit stop and conducting correlation analysis using random forest regression analysis to check the transit ac-
cessibility and dependency of socio-economic attributes on public transit. This study reviews the Huntsville existing transit system, the accessibility to essential amenities, and the distribution of these services with the city due to increasing need for public transportation. This review offers insightful information, which helped complete this analysis and shape future transit planning.
Chapter 3. Methodology

3.1 Proximity Analysis-Near Tool

A rating system from zero to four was developed, with zero denoting non-accessibility and ratings from one to four denoting different degrees of accessibility. Each of these accessibility scores represents a certain proportion of the total accessibility, with higher scores representing greater accessibility. The exact proportion of each score was calculated as the number of amenities receiving that score divided by the total number of amenities. Thus, each accessibility proportion gives the percentage of total amenities that falls into that accessibility category. Proportion is mathematically estimated as shown in Equation (3.1).

\[
\text{Proportion} \, (\%) = \left( \frac{\text{Frequency of each accessibility score}}{\text{Total Frequency}} \right) \times 100
\]  

(3.1)

Amenities within 800 meters of transport stops were considered accessible. The closest proximity to transport stops is indicated by a score of four, while a score of one indicates restricted accessibility. A tabular column was generated to summarize the frequency of accessibility score alongside the percentage accessibility index for all amenities, providing a comprehensive understanding of transit accessibility across essential services in Huntsville.
The distance from each census block to necessary services including restaurants, offices, recreational facilities, industrial parks, and residential complexes should be considered in a detailed public transit analysis. It is feasible to assess how well public transportation satisfies Huntsville citizens’ needs by looking at how easily these amenities are accessible from the system.

The ArcGIS Near tool was used to calculate the distance between each necessary amenities and the closest transit stop. Based on their proximity, the obtained distances were then divided into accessible and non-accessible categories. This process not only provided a distance-based measure of accessibility, but also allowed the computation of the accessibility proportion for each score, enhancing our understanding of the distribution of transit accessibility across Huntsville.

3.2 Regression Analysis

This study involved a data analysis of information collected from the Census Bureau of the United States, focusing on select attributes of block group populations within Huntsville. The data were gathered based on employment status, transportation modes to work, racial groupings, educational attainment, and poverty levels. To assess the accessibility of public transit stops within Huntsville city limits, a ‘near distance’ calculation was performed for each block group using the Near tool from ArcGIS tools, with reference to the nearest transit stops [22].

An exploration of the relationship among these data points was carried out. Initially, a linear relationship was sought, using the Ordinary Least Squares (OLS) method to compute results. However, due to the noise inherent in the
data, the model accuracy was insufficient. Correlation analysis was then used to investigate the association between ‘near distance’ and other dependent variables, but it failed to produce meaningful results.

Consequently, the data were analyzed using nonlinear regression analysis, wherein the Random Forest regression analysis performed good compared to OLS regression method. Random Forest regression analysis utilizes the bagging method with the training data. Bagging is a combination approach that mitigates overfitting in data points. In comparison with the decision tree, the Random Forest regression method is better suited for handling overfit data [6] [23]. By creating multiple decision trees and amalgamating their results, more accurate and stable predictions are facilitated.

The accuracy of the machine learning model was subsequently assessed through computations of Mean Square Error (MSE), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE) [24].

- **Mean Square Error (MSE):** This is computed as the squared mean difference combined with Mean Absolute Error (MAE), utilizing sklearn’s mean square error method. The formula is given as,

\[
MSE = \frac{1}{N} \sum_{i=1}^{N} (Actual\ Values_i - Predicted\ Values_i)^2
\]  

(3.2)

where \( N \) is the total number of observations.
• **Root Mean Square Error (RMSE):** This value is derived from the standard deviation of prediction errors. RMSE, the root of MSE, is employed to ascertain the accuracy of the model.

• **Mean Absolute Error (MAE):** MAE is the measure of error between actual and predicted values. It serves as a tool to gauge the model’s performance and to work on minimizing errors in the dataset. The formula is given as

\[
MAE = Actual\ Values - Predicted\ Values.
\]  

Within the context of our Random Forest regression analysis, a detailed evaluation of the true and predicted values allowed for an exploration into “feature importance”, an inherent strength of this method. As such, a threshold of 0.025 was chosen for selecting features. This decision was driven by the need to balance the model’s simplicity with its predictive accuracy, effectively minimizing the risk of overfitting. It assures the model’s applicability to unseen data while retaining the features significantly contributing to the variance explanation.

This strategy led to the identification of the key features from the dataset that surpassed the threshold, shedding light on the most influential variables correlating with “near distance”. For better comprehension, these selected important features were grouped and depicted through graphical illustrations. Such scrutiny into these feature importance plots gives us a deeper understanding of the factors substantially impacting “near distance”, which, in turn, enriches the entire analytical process.
Statistical analysis of p value and confidence interval method involved examining the statistical importance of each variable and its impact on the model’s prediction ability, as indicated by their respective p-values and confidence intervals. Each attribute’s p-value was determined, providing a measure of statistical significance or the likelihood of receiving the observed data if the null hypothesis is true. A lower p-value often indicates more evidence to reject the null hypothesis, showing that the feature has a significant impact on near distance predictions.

3.3 Optimized Hot Spot Analysis

The Hot Spot Analysis methodology attempts identifying statistically significant Spatial clusters of high values (hot spots) and low values (cold spots) in relation to essential amenities such as restaurants, places of employment, recreational facilities, industrial parks, and residential buildings, hospitals, and medical facilities. This program automatically aggregates incident data, chooses the proper analysis scale, and makes multiple testing and spatial dependence corrections. It analyzes the data to determine optimal settings for hot spot analysis. These settings can be fully customized using the Hot Spot Analysis tool.

The calculated parameters utilized for the best hot spot analysis are presented as messages while the tool is running. The “How Optimized Hot Spot Analysis Works” documentation provides specifics on the relevant procedures and algorithms. For each feature in the Input Feature Class, the tool generates a new Output Feature Class with a z-score, p-value, and confidence level bin (Gi_Bin). It also has a variable (NNeighbors) that lists how many neighbors each feature con-
sidered when making its computations. The List By Charts tab on the Contents pane allows access to a histogram charting the value of the variable examined (either the Analysis Field or the event count within each polygon) as part of the tool’s output. The False Discovery Rate (FDR) correction approach is used to account for multiple testing and spatial dependence when identifying statistically significant hot and cold locations in the Gi_Bin field. Features with a Gi_Bin value of 0 are not statistically significant in terms of clustering, while features in the +/-3 bins are significant at the 99 percent confidence level, +/-2 bins at the 95 percent level, and +/-1 bins at the 90 percent level.
Chapter 4. Experimental Results

4.1 Regression Analysis

In the Ordinary Least Squares (OLS) regression analysis as seen in Table 4.1, the Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Error (MAE) values of the attributes under consideration were computed. “Schooling” had the lowest MSE of 2.29, RMSE of 1.51, and MAE of 1.17, suggesting a relatively better predictive performance compared to other attributes such as “Employment”, “Means of transportation to work (MOT)”, “Social groups or races”, and “Poverty”.

However, the OLS regression model’s relatively higher error values indicate a potential presence of data noise and complex relationships that it could not adequately capture. This necessitated the employment of the Random Forest regression model for a more comprehensive understanding of the attribute significance.

The results of the random forest regression analysis provide valuable insights into the predictors of “near distance” in our study of public transit stop accessibility in Huntsville.

The Random Forest regression model as shown in Table 4.2 offered a marked improvement in predictive accuracy over the OLS model. For instance,
The “Employment” attribute, with an MSE of 0.36, RMSE of 0.60, and MAE of 0.45, demonstrated a substantial reduction in error rates compared to the OLS model. Similar improvements were noted across the remaining attributes.

Figure 4.1 presents the results of the Random Forest feature importance analysis, which identifies attributes that have a significant influence on the model’s performance with a threshold above 0.025.

Table 4.3 provides a detailed account of the 5 significant attributes out of the original 39 based on their p-values and confidence intervals. Attributes like “State government workers”, “Regular high school diploma”, and “Professional
Figure 4.1: Results from Random Forest feature importance with threshold above 0.025.

Table 4.3: Results showing important features p-value and confidence interval.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Coefficients</th>
<th>P-Value</th>
<th>Confidence Interval: Lower</th>
<th>Confidence Interval: Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>State government workers</td>
<td>0.0069</td>
<td>0.0414</td>
<td>0.0002</td>
<td>0.0136</td>
</tr>
<tr>
<td>Regular high school diploma</td>
<td>0.0025</td>
<td>0.0170</td>
<td>0.0004</td>
<td>0.0046</td>
</tr>
<tr>
<td>Professional school degree</td>
<td>0.0087</td>
<td>0.0282</td>
<td>0.0009</td>
<td>0.0164</td>
</tr>
<tr>
<td>Poverty level Under .50</td>
<td>-0.0030</td>
<td>0.0086</td>
<td>-0.0052</td>
<td>-0.0007</td>
</tr>
<tr>
<td>Population used Car, truck, or van</td>
<td>0.0007</td>
<td>0.0302</td>
<td>0.0007</td>
<td>0.0014</td>
</tr>
</tbody>
</table>

school degree” showed a significant influence on the prediction of ‘near distance’ based on their p-values and confidence intervals.

Firstly, the “State Government Workers” attribute holds considerable weight in this context, demonstrated by its coefficient of approximately 0.0069. This implies that for every unit increase in the number of state government workers, there’s a corresponding increase of 0.0069 units in near distance, holding all other
factors constant. This finding is statistically significant, as shown by a p-value of 0.0414, less than the 0.05 significance level. The 95% confidence interval falls between 0.0002 and 0.0136, providing a degree of assurance regarding the precision of this coefficient.

Another significant attribute is “Regular High School Diploma”, with a coefficient of approximately 0.0025. It indicates that an additional person holding a regular high school diploma contributes to an increase in the near distance by roughly 0.0025 units. The p-value stands at 0.0170, confirming the statistical significance of this attribute. The 95% confidence interval lies between 0.0004 and 0.0046, which further bolsters the reliability of this result.

The “Professional School Degree” attribute also carries weight, with a coefficient of about 0.0087. The significance of this attribute is confirmed with a p-value of 0.0282. The 95% confidence interval is within the range of 0.0009 and 0.0164, showing a high degree of certainty for this result.

Interestingly, the attribute “Poverty Level Under .50” exhibits a negative correlation with the dependent variable near distance, evident by a coefficient of -0.0030. The p-value of 0.0086 suggests statistical significance of this attribute. The 95% confidence interval falls between -0.005231 and -0.0007, thus confirming this finding.

Finally, “Population Used Car, Truck, or Van” plays a role as well, exhibiting a coefficient of approximately 0.000779. This suggests a minor increase in the near distance for every unit increase in this population. This result holds statistical significance with a p-value of 0.0302. The 95% confidence interval for
this variable is between 0.00007 and 0.0014, offering assurance about the accuracy of this estimate.

In conclusion, the Random Forest regression analysis demonstrates predictive performance in determining “near distance”, considering diverse attributes. These identified significant attributes are expected to guide future efforts aimed at enhancing the planning and accessibility of public transit stops in Huntsville.

4.2 Proximity Analysis-Near Tool

The utilization of ArcGIS’s Near tool for performing a proximity analysis is instrumental in establishing the accessibility scores for each essential service. These scores hinge on the distance of these services from the closest transit stop, considering an 800-meter radius within the transit network. In essence, these scores offer an understanding of how near or far these services are from public transit, hence gauging their level of accessibility. The scoring metric is on a scale of 0 to 4, with 4 being indicative of optimal accessibility to a transit stop, while a score of 1 point to poor accessibility. On this scale, a score of 0 reflects the absence of certain services within the 800-meter network. The below Table 4.4 shows the accessibility score based on distance.

This method aids in comprehending the spatial distribution of essential services in addition to their accessibility to public transit, which could influence urban planning and resource allocation. Additionally, assessing the ratings can show places where accessibility needs to be improved, ensuring that all the residents have equal proximity to essential services. The mean, median, and standard
Table 4.4: Accessibility Score and corresponding Proximity Distance.

<table>
<thead>
<tr>
<th>Accessibility Score</th>
<th>Proximity Distance (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not accessible</td>
</tr>
<tr>
<td>1</td>
<td>600m – 800m</td>
</tr>
<tr>
<td>2</td>
<td>400m – 600m</td>
</tr>
<tr>
<td>3</td>
<td>200m – 400m</td>
</tr>
<tr>
<td>4</td>
<td>0m – 200m</td>
</tr>
</tbody>
</table>

deviation of the scores were derived for a more comprehensive investigation, providing details about overall accessibility trends and deviation in service proximity within the studied area.

Table 4.5: Accessibility score for all essential services in Huntsville.

<table>
<thead>
<tr>
<th>Accessibility Score</th>
<th>Restaurants</th>
<th>Recreational facilities</th>
<th>Medical facilities</th>
<th>Industrial parks</th>
<th>Grocery/Retail</th>
<th>Apartment complexes</th>
<th>Educational institutions</th>
<th>Hospitals</th>
<th>All essential services</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>170</td>
<td>63</td>
<td>18</td>
<td>23</td>
<td>71</td>
<td>68</td>
<td>3</td>
<td>1</td>
<td>427</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>5</td>
<td>8</td>
<td>1</td>
<td>10</td>
<td>15</td>
<td>8</td>
<td>0</td>
<td>114</td>
</tr>
<tr>
<td>3</td>
<td>124</td>
<td>14</td>
<td>20</td>
<td>2</td>
<td>33</td>
<td>35</td>
<td>4</td>
<td>0</td>
<td>241</td>
</tr>
<tr>
<td>4</td>
<td>103</td>
<td>12</td>
<td>25</td>
<td>3</td>
<td>86</td>
<td>46</td>
<td>3</td>
<td>3</td>
<td>192</td>
</tr>
</tbody>
</table>

Table 4.6: Proportion of accessibility score for all essential services in Huntsville.

<table>
<thead>
<tr>
<th>Accessibility Score</th>
<th>Restaurants(%)</th>
<th>Recreational facilities(%)</th>
<th>Medical facilities(%)</th>
<th>Industrial parks(%)</th>
<th>Grocery/Retail(%)</th>
<th>Apartment complexes(%)</th>
<th>Educational institutions(%)</th>
<th>Hospitals(%)</th>
<th>All essential services(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28.11</td>
<td>67.92</td>
<td>21.85</td>
<td>36.81</td>
<td>21.97</td>
<td>16.36</td>
<td>30.00</td>
<td>25.00</td>
<td>25.76</td>
</tr>
<tr>
<td>1</td>
<td>6.60</td>
<td>0.0</td>
<td>1.25</td>
<td>0.8</td>
<td>0.27</td>
<td>1.40</td>
<td>0.0</td>
<td>0.0</td>
<td>1.18</td>
</tr>
<tr>
<td>2</td>
<td>12.56</td>
<td>5.31</td>
<td>18.95</td>
<td>2.45</td>
<td>7.65</td>
<td>9.62</td>
<td>0.0</td>
<td>0.0</td>
<td>10.00</td>
</tr>
<tr>
<td>3</td>
<td>21.39</td>
<td>16.89</td>
<td>21.16</td>
<td>5.46</td>
<td>15.78</td>
<td>16.71</td>
<td>15.00</td>
<td>0.0</td>
<td>20.28</td>
</tr>
<tr>
<td>4</td>
<td>34.22</td>
<td>15.76</td>
<td>10.76</td>
<td>5.46</td>
<td>41.10</td>
<td>35.10</td>
<td>20.00</td>
<td>75.00</td>
<td>20.00</td>
</tr>
</tbody>
</table>
Tables 4.5 and 4.6 provide a comprehensive view of accessibility scores across various essential services in Huntsville. All essential services had the highest non-accessible rating (35.94%) but also a considerable proportion of high accessibility (33%). Restaurants showed similar trends, with 30.14% non-accessible, but 34.22% scoring 4. In contrast, recreational facilities had a worrying 67.02% non-accessible rating, but 27.65% had reasonable or high accessibility. Medical facilities showed a promising distribution, with low non-accessibility (21.95%) and high accessibility (65.84%) scores. Industrial parks are predominantly non-accessible (86.84%), indicating a severe accessibility issue. Grocery stores and apartment complexes showed a dichotomous distribution, with significant proportions at both ends of the accessibility spectrum. Colleges and universities exhibited a balanced distribution, with 30% each at the extremes and 40% moderately accessible. Finally, hospitals proved highly accessible (75%), though attention is needed for the non-accessible 25%. These results indicate a pressing need for improved urban planning to ensure equal access to essential services across Huntsville.

The results from the accessibility score analysis reveal vital observations regarding the spatial distribution of essential services and their accessibility to public transit within the city of Huntsville.

Briefly, while many services demonstrate a reasonable level of accessibility, others reveal noticeable deficiencies. Over a third of all essential services within the city scored zero, indicating poor access from transit stops. This points to areas in the city where the spatial arrangement of transit stops and essential
services presents significant obstacles to residents dependent on public transit. However, it is reassuring to note that approximately one-third of services fall under the highest level of accessibility. This highlights areas where city planning has successfully integrated essential services with public transit routes.

When analyzed individually, the data offer nuanced insights into each category of essential services. Restaurants, medical facilities, grocery stores, and apartment complexes reflect a well-dispersed accessibility spectrum, with services at various distances from transit stops. It’s essential to improve the accessibility of restaurants and grocery stores, as they directly influence the residents’ quality of life and well-being.

Recreational facilities and industrial parks present a stark contrast to the previous categories. Most of these services are inaccessible from transit stops, posing a severe accessibility issue. The challenge is particularly pronounced in the case of industrial parks, with an overwhelming 86.84% scoring zero. This can limit labor mobility and potentially inhibit the city’s economic growth.

The accessibility scenario for colleges and universities falls under the moderate to high accessibility score range. However, the 30% that are inaccessible need attention to ensure equal access to education for all residents. Hospitals depict an encouraging picture, with 75% falling under the highest accessibility score, a promising finding considering hospitals’ vital role in public health.

In Table 4.7, “Weighted Frequency and Average Accessibility Rating of Various Services in Huntsville”, we have effectively synthesized the accessibility scores of diverse services available in Huntsville, such as restaurants, recreational
facilities, medical facilities, industrial parks, grocery stores, apartment complexes, colleges and universities, and hospitals. The scoring spectrum spans from 0, denoting low accessibility, to 4, representing high accessibility.

This table was assembled by analyzing the frequency of each accessibility score for every service and calculating the respective proportions against the total frequency. Subsequently, the weighted frequencies were derived by multiplying each score by its respective frequency. Finally, the average rating was determined by dividing the sum of all weighted frequencies by the total frequency.

Several observations emerge from an examination of the data collated in Table 4.7:
• The hospitals in Huntsville boast the highest average accessibility score, thereby suggesting that they are readily accessible to the inhabitants of the city.

• Conversely, the industrial parks manifest the lowest average accessibility score, indicating a potential area of concern for the local authorities.

• Services like grocery stores and apartment complexes showcase high accessibility scores, reflecting the city’s commitment to ensuring easy availability of everyday necessities for its residents.

• However, a relatively lower average score for recreational facilities might suggest that more focus is required to enhance the accessibility of these services.

In conclusion, this research provides an extensive perspective of the accessibility scenario in Huntsville, revealing areas of achievement and spaces for growth. A significant need exists for resource allocation and creative urban design to improve public transit connectivity, particularly to the farther away essential services. The city might greatly enhance the standard of living for its citizens by resolving these problems, particularly for those who depend on public transportation. Additionally, improving accessibility might promote social fairness, better health outcomes, and stimulate Huntsville’s economy.
4.3 Optimized Hot Spot Analysis

Optimized Hot Spot Analysis in ArcGIS Pro is an advanced spatial analysis tool that evaluates the spatial relationships between features to uncover statistically significant patterns in our data. Using this method, results interpret the accessibility of essential amenities regarding public transit coverage in the study area. Hot spots are areas where high values of the evaluated attribute are clustered, indicating that these regions have better access to essential services within public transit coverage. Cold spots, on the other hand, are zones where low values of the attribute cluster together, indicating poor access to essential services near transit areas. To ensure a fair distribution of resources to the community, specific locations may require improvements in transit accessibility.

The results below of the hot spot analysis reveal the relationship between accessibility and public transit network coverage with all essential services. Red and Yellow represent hot spots, indicating areas with excellent accessibility to essential services via the transit network. Conversely, blue symbolizes cold spots, denoting areas with limited accessibility. Pale yellow highlights regions with some significance, while the small grey points suggest no significant relationship with the transit network. This analysis helps visualize spatial patterns and identify areas for potential improvements in transit-oriented development.

The hot spot analysis for all essential services in the Huntsville city, as depicted in Figure 4.2, illustrates that the red spots, signifying significant hot spots, are primarily located in the city center extending towards Huntsville North.
and East Huntsville region. On the contrary, the blue spots, which denote cold spots, are prominently seen in the periphery of the city, particularly towards the South Huntsville, Mountain Cove, New Hope, Harvest, and Wheelers area. This geographical dichotomy implies a stark disparity in the public transit service availability, with about 35% of essential services being inaccessible via public transit. The analysis signifies an immediate need for addressing this gap to ensure equitable access to essential services throughout the city.

The hot spot analysis for apartment complexes, presented in Figure 4.3, mirrors the pattern observed for essential services. The apartment complexes located in the South Huntsville, Mountain Cove and Wheelers area parts of Huntsville are marked as cold spots, pointing towards the lack of efficient transit
services. As these areas are witnessing substantial city expansion and development, an increase in transit accessibility could motivate residents to use public transportation instead of private vehicles, reducing traffic congestion and promoting sustainable commuting practices.

Figure 4.4 reveals the hot spot analysis for grocery stores, wherein a substantial number are within the reach of public transit. However, South Huntsville and Mountain Cove region of the city emerges as a significant cold spot, emphasizing the need for an upgrade in transit services. Ensuring accessible transit service to these stores would not only cater to the residents’ needs but could also contribute to reducing private vehicle usage, providing a more sustainable and efficient transportation solution.
Figure 4.4: Hot spot analysis of Grocery stores in Huntsville city limits.

The hot spot analysis for industrial parks, as shown in Figure 4.5, presents an interesting scenario. Most of the industrial parks are labeled as ‘not significant,’ primarily due to their location outside the city limits and the lack of efficient public transit connectivity. This observation calls for exploring alternate modes of transportation, such as shuttle services, to facilitate workers commuting to these parks.

Figure 4.6 provides the hot spot analysis for medical facilities within the city. The results indicate that while most of the facilities are within accessible transit routes, there are a few that lack adequate connectivity. Like the observations made for other services, the areas that require significant improvement predominantly lie towards the South Huntsville and Mountain Cove region.
of Huntsville, reemphasizing the need for transit network enhancement in these parts.

As depicted in Figure 4.7, the hot spot analysis for recreational facilities indicates that a significant number of these facilities, particularly in the south Huntsville, New Hope, and Mountain Cove regions of Huntsville, are not adequately serviced by public transit. This underscores the requirement for reconsidering transit service planning and development to accommodate these facilities and enable their access to the wider population.

Figure 4.8 presents the hot spot analysis for restaurant chains in Huntsville. While the city center regions of Huntsville north, Research Park Area and east Huntsville showcases a significant number of hot spots, meaning they are easily
Figure 4.6: Hot spot analysis of Medical facilities in Huntsville city limits.

accessible via public transit, peripheral regions, especially the south and west region of South Huntsville, Harvest, Mountain Cove, and New Hope, reveal major cold spots with few spots towards east regions of New Market. Given the importance of these establishments in the city’s social and economic fabric, it is crucial to address these service gaps, ensuring an inclusive and efficient transit network that caters to all sections of the city.

The combined analysis of various essential services in Huntsville, as presented through our comprehensive hot spot analysis, clearly indicates a disparity in transit accessibility. A significant number of services, especially in the southern and western parts of South Huntsville, Harvest, Mountain Cove, and New Hope of the city, are underrepresented in the public transit network. These findings
Figure 4.7: Hot spot analysis of Recreational facilities in Huntsville city limits.

reveal the observed demographic shift in the population density towards these regions, further underlining the urgency to enhance transit services here.

Moreover, the insufficient transit connectivity in industrial parks, located predominantly towards the southwest regions in Wheeler area, accentuates the need for alternate transportation solutions to ensure worker accessibility. By proactively addressing these disparities, not only could the city meet the needs of its expanding population but also optimize its transit system.

Therefore, a thorough re-evaluation and reformation of the current public transit network in Huntsville are imperative. With significant planning efforts and a focus on service accessibility, it is possible to bridge these service gaps, thereby promoting more equitable transit services. By doing so, the city can encourage
Figure 4.8: Hot spot analysis of Restaurants in Huntsville city limits.

the use of public transit, subsequently reducing congestion and the dependence on private vehicles, contributing to a more sustainable city environment, and improving the overall quality of life for its residents.
Chapter 5. Conclusion and Future Scope

5.1 Conclusion

The analysis of Huntsville city, Alabama, reveals significant disparities in public transit accessibility, particularly in South Huntsville, Harvest, Mountain Cove, and New Hope. Despite demographic diversity, reliance on private vehicles is prevalent, indicating room for improvements in public transit services. Economic disparities and influence of transit coverage on demographic patterns necessitate tailored interventions.

In conclusion, the comprehensive study conducted on Huntsville city, Alabama, reveals various insights about the city’s demographic composition, spatial distribution of essential services, reliance on different modes of transportation, and service area optimization. The core findings from the study can be summarized as follows.

- **Disparity in Transit Accessibility:** The analysis reveals significant disparities in public transit accessibility to essential services, particularly in the southern and western parts of South Huntsville, Harvest, Mountain cove, and New Hope. Industrial parks are also identified as areas in need of better transit solutions due to their peripheral locations and lack of efficient public transit connectivity. These insights underscore the need for more resource
allocation and urban design efforts to improve transit accessibility in these areas.

- **Diversity and Dependence:** The city exhibits notable diversity across various demographic variables, including race, educational attainment, and means of transportation to work. Despite this diversity, there’s a prevalent reliance on private vehicles for commuting, suggesting the need for enhancements in public transportation services.

- **Economic Disparities and Transit Coverage:** Economic disparities exist within Huntsville, particularly around the outskirt’s region of Huntsville city, indicating the need for targeted interventions to alleviate poverty and improve living conditions. The influence of public transit coverage on these demographic patterns is evident and needs to be considered when improving and expanding transit network coverage.

- **Analysis and Prediction:** Both service area analysis and random forest regression analysis were applied to predict ‘near distance’ considering various factors. The Random Forest model demonstrated superior predictive accuracy, emphasizing the importance of advanced analytical models in extracting meaningful insights from complex urban data. Significant attributes contributing to the prediction of ‘near distance’ were identified, which are crucial for understanding public transit stop accessibility in Huntsville. These attributes include the prevalence of state government workers, the proportion of individuals holding a regular high school diploma.
and a professional school degree, the segment of the population living under a poverty level of .50, and the percentage of the population using a car, truck, or van, which are crucial for understanding public transit stop accessibility in Huntsville.

- **Proximity Concerns:** The proximity analysis indicates that certain services, like hospitals and grocery stores, are near transit stops, facilitating access for residents. However, considerable accessibility issues exist for industrial parks and recreational facilities. These findings emphasize the necessity for targeted efforts to improve public transit connectivity to essential services.

Based on these conclusions drawn from our study, it is evident that Huntsville’s public transit network calls for a comprehensive review and subsequent improvements. The focus should primarily lie on mitigating service disparities, resolving accessibility challenges, and fostering an environment of inclusivity. This wealth of insights serves as a tool for policymakers and urban planners, enabling them to devise strategies aimed at enhancing transit services and accessibility, thereby raising the standard of living for Huntsville’s residents. Future exploration should broaden this analysis, considering factors such as transit service frequency and pedestrian-oriented infrastructure, for a more holistic understanding of Huntsville’s accessibility landscape. Implementing such an approach would help cultivate a more equitable, inclusive, and efficiently functioning urban ecosystem, thereby enriching the sustainability and economic resilience of Huntsville.
5.2 Future Scope

In the continuation of this research, several promising avenues present themselves for further exploration. A comparative analysis with other cities and regions could shed light on unique urban patterns and strategies that could be adapted for Huntsville. Additionally, incorporating temporal dimensions, such as examining accessibility during peak and off-peak hours, would provide a more nuanced understanding of the dynamic transit needs of the population.

Taking into consideration more variables like transit service regularity, reliability, the pedestrian-friendly nature of routes, including sidewalks, and the effect of traffic congestion would help to broaden our comprehension of the city’s transit accessibility situation. Complementing this, qualitative research methods involving interactions with public transit users, non-users, and transit service providers could bring to light important details that might not be noticed with just a numerical analysis.

Policy interventions informed by this research should be carefully monitored and assessed to understand their effectiveness in bridging accessibility gaps and meeting the transit needs of Huntsville’s residents. Furthermore, leveraging advanced predictive modeling techniques, including machine learning and AI algorithms, could offer more sophisticated tools to understand and interpret complex data relationships.

Lastly, it is crucial to recognize the profound influence of technological advancements on urban transit. For future inquiries, it is recommended to delve
into the potential impact of emergent technologies such as ridesharing platforms, autonomous vehicles, and intelligent transit systems. Investigating these aspects could significantly enhance our comprehension of urban transit accessibility in Huntsville, while also informing the development of more effective and equitable transportation policies. Such examinations could ultimately shape the future trajectory of public transportation within the city.
References


