A GIS-BASED WALKABLE SERVICE AREA ANALYSIS (WSAA) MODEL FOR ASSESSMENT OF SPATIAL ACCESSIBILITY EQUITY: A CASE STUDY IN HUNTSVILLE, ALABAMA

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I would like to dedicate my thesis to my respected parents for their endless inspiration, love, and support. Wherever I have reached my career today, it is because of them. I am also grateful to my thesis supervisor Dr. Jacob Oluwoye, for his unconditional support and guidance. I learned a lot from him. Furthermore, I would like to sincerely thank my thesis committee members; Dr. Deden Rukmana, Dr. Emily Erickson, and Dr. Mahbub Hasan. Besides, I extend my thanks to faculty, staff, and students of the Department of Community and Regional Planning for providing all the required assistance and support throughout the master's degree towards accomplishing my thesis work.

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Huntsville is entirely an auto-oriented city like many other cities in Alabama, USA. The only public transport is the shuttle bus, but it is time-consuming and unavailable at night or on holidays. For these reasons, it is difficult for the disabled, elderly, and people who have no car to move from one place to another. Furthermore, the roads are not suitable for walking. The purpose of the study is to examine the factors that affect walkability and accessibility, develop an updated Walkable Service Area Analysis(WSAA) model, and recommend potential strategic actions concerning socioeconomic status(SES), population density, and land use of Huntsville City. For examining the characteristics of the built walking environment, a walkable service area analysis(WSAA) map was generated using the destination density metrics, and then the census tract areas were categorized based on the walkability score of the map. Subsequently, the reliability and validity of the WSAA model were examined by conducting an online walkability audit. The Z-test with a value of 0.089 suggests no significant difference between the measured walkability scores and online walkability audit scores. At the next step, the relationship of GIS-model-generated walkability scores with socioeconomic status(SES) (median household income and poverty percentage), population density, and land use cover were examined. Finally, this thesis recommends the potential solutions to walkability problems in Huntsville based on the analysis. The results of the analysis suggest that population density and poverty percentage have a strong positive correlation with walkability, and median household income has a

medium negative correlation with walkability. Moreover, empirical analysis reveals that walkability tends to decrease on cultivated croplands, hay/pasture, and woody wetlands. This thesis concludes that rather than focusing on street furniture, scattered and higher intensity mixed land-use development should be prioritized for developing walkability because these kinds of development automatically emphasize initiating a long-term pedestrian master plan in Huntsville.

KEYWORDS: Walkability, Geographic information system, Walk Score®, Spatial Equity, Spatial Accessibility.

TABLE OF CONTENTS

CERTIFICATE OF APPROVAL ..... **i**

ABSTRACT AND KEYWORDS ..... **iv**

ACKNOWLEDGMENTS ..... **vii**

CHAPTER 1-INTRODUCTION **1**

Background 1

Statement of the Problem 5

Purpose and Objectives of the Study 7

CHAPTER II-REVIEW OF LITERATURE **8**

Walkability theory 8

Walkability Analysis Approach with GIS 12

Validation of Walk Score 14

Notion of spatial equity 15

The notion of accessibility 16

CHAPTER III-DESIGN AND METHODOLOGY **17**

Study Area 19

Develop an updated GIS model 20

Validation of WSAA Score 25

Analyzing Socio-demographic factors and land use cover with walkability.....26

CHAPTER IV-RESULTS AND DISCUSSION.....31

Analysis 31

Results.....34

Discussion..... **Error! Bookmark not defined.**

CHAPTER V- CONCLUSIONS AND RECOMMENDATIONS.....53

Recommendations.....53

Conclusion 56

BIBLIOGRAPHY.....58

APPENDICES.....64

Appendix A.....64

Appendix B.....66

LIST OF TABLES

Table 1: Data Sources of GIS data layers used for Creating WSAA Map 20

Table 2: Walking distances and weights for the Selected Destination Points 22

Table 3: Roads within Huntsville: length more than 5 miles 25

Table 4: Z-Test: WSAA generated walkability score and Walk Score® 26

Table 5: Land use cover of Huntsville City 28

Table 6: Majority land cover by the total number of census tracts 30

Table 7: Descriptive Statistics of walkability score and walkability factors 31

Table 8: Bivariate Correlation of Walkability score and walkability factors 32

Table 9: Classified Walkability Score Areas 36

Table 10: Walkability scores, population density, and socioeconomic factors of census tracts that are covered by cultivated croplands 38

Table 11: Walkability scores, population density, and socioeconomic factors of census tracts that are covered by open space-developed land 42

Table 12: Walkability scores, population density, and socioeconomic factors of census tracts covered by deciduous forest. 45

Table 13: Walkability scores, population density, and socioeconomic factors of census tracts that are covered by hay/pasture 51

LIST OF FIGURES

Figure 1: Study Area 19

Figure 2: Walkable Service Areas measured for Groceries 23

Figure 3: Walkable Service Areas measured for Schools 23

Figure 4: Walkability Score Map of Huntsville City 23

Figure 5: Walkability Score Map by census tracts of Huntsville City 24

Figure 6: 2016 Land Use Cover Map of City of Huntsville, Alabama 27

Figure 7: 2016 Majority Land Use Cover Map and Walk Score Concentration Map by Census Tracts, City of Huntsville, Alabama, USA 29

Figure 8: Scatter plot and regression Line of Walkability Score and Land Cover Use 33

Figure 9: Land Use by Zoning Interactive Map of Census Tract 212 37

Figure 10: Land Use by Zoning Interactive Map of Census Tract 31 40

Figure 11:Land Use by Zoning Interactive Map of Census Tract 12 41

Figure 13: Land Use by Zoning Interactive Map of Census Tract 19.03 43

Figure 13: Land Use by Zoning Interactive Map of Census Tract 27.01 43

Figure 14: Land Use by Zoning Interactive Map of Census Tract 19.01 44

Figure 15: Land Use by Zoning Interactive Map of Census Tract 106.12 45

Figure 16: Land Use by Zoning Interactive Map of Census Tract 2.01 46

Figure 17: Land Use by Zoning Interactive Map of Census Tract 29.12 48

Figure 18: Land Use by Zoning Interactive Map of Census Tract 29.22 48

Figure 19: Land Use by Zoning Interactive Map of Census Tract 19.02 48

Figure 20: Land Use by Zoning Interactive Map of Census Tract 18.01 48

Figure 21: Land Use by Zoning Interactive Map of Census Tract 27.22 50

Figure 22: Land Use by Zoning Interactive Map of Census Tract 108 50

Figure 23: Land Use by Zoning Interactive Map of Census Tract 4.03 50

Figure 24: Land Use by Zoning Interactive Map of Census Tract 109.01 50

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CHAPTER 1

INTRODUCTION

Background

Huntsville city is located in the northern part of Alabama. According to Indeed's city rankings, after San Jose-Sunnyvale-Santa Clara, CA(22.7%), around 17.8 percent of total tech job postings are from Huntsville. Huntsville is recently recognized as a national technology leader. However, the city population, as well as tech companies, are rapidly growing around the city. According to the US census bureau, if the population growth trend continues, Huntsville could be the most populous city in Alabama by 2021. It can be said that, in the future, Huntsville could be converted to a highly developed, populous city from a low-density city. Today it is a well-established statement that one of the major problems of many developed and populous cities is uncontrolled urbanization. The negative consequences of Urban sprawl are environmental pollution, increased traffic, human health, increase in public expenditure, lack of open space, and many others. For mitigating these negative effects, smart growth is one of the most prevalent approaches among different professionals like planners, engineers, environmentalists, architects, and others. "Creating walkable neighborhoods" is one of the ten main principles of the smart growth approach. In few words, creating a suitable walking environment is one of the major factors that can mitigate the detrimental effects of future potential urban sprawl.

Understandably, the walkability concept in these locations is relatively new because, for a long time, the city and its economy are running, depending, and growing based on the personal automobile as a primary mode of transportation. But due to different benefit positive

outcomes in other walkable cities and control urbanization, researchers started thinking of the walkability concept in these car-dominant cities as a serious, legitimate transportation mode rather than consider walking as only recreational or health purposes [1]. Although the topography in some regions of the city is not quite suitable such as the hills east of Huntsville, almost all other areas have an approximate slope below 10% [2], there is enough opportunity to develop an areawise small scale pedestrian plan. Currently, Huntsville is one of the most automobile-dependent cities in the USA. Transportation becomes very difficult for physically, economically, and socially disadvantaged people in these automobile-dependent cities because they cannot afford a car or cannot drive a vehicle for their physical condition.

Automobile dependency has many negative land-use impacts[3]. It enhances the amount of land covered for roads and parking, which has economic, social, and environmental costs[3]. Overdepency on cars creates detrimental effects on health and sometimes on the environment. For example, greenhouse gas emissions had increased drastically for the overuse of automobiles in the city of Edrine in turkey[4]. In addition, it increases traffic congestion or traffic jam and roadway risk. Experts pointed out that the overuse of automobiles results in excessive greenhouse gas emissions in a developed city. Also, it increases parking facility costs and accident damages[3]. On the other hand, walkable towns are suitable for all classes of people regarding the poor, elderly, and children[5]. Besides, walkable neighborhoods are more socially engaged [5]. Although walking is considered the slowest transportation mode, it helps increase the overall convenience, comfort, and affordability of access to destinations[3].

Moreover, improving the walking environment helps gain social equity and economic opportunity objectives[3]. It is also beneficial for health, which helps people to keep healthy and disease-free. It enhances economic development, accessibility, efficient land use,

community livability, consumer cost savings, public cost savings (reduced external costs), and support for equity objectives[3].

This thesis has five chapters. The first chapter briefly discusses the topic, study area, research background, problem statement, goals, objective, and a clarified map out of the thesis. In addition, the first chapter includes the following analysis of why the WSAA method was chosen over the other methods in Huntsville.

This thesis measures walkability in Huntsville city. Pre-defined spatial units(i.e., Census Tracts), was used for the walkability measurement. Different methods can be used for walkability measurement. The method that the researcher use depends on the goals of the research and the resources available. For example, the health-related Researcher might interest in either people walk enough for physical health. They do not need to consider distance, location, or purpose of walking for this research. This research mostly relies on different surveys and follows a qualitative approach for the output result. On the other hand, transportation modelers might focus on the number of walking trips. Moreover, another research topic can be analyzing and designing a physical walking environment, including all street infrastructure. The method of the research might be sidewalk and other street infrastructure surveys. This thesis followed the Geographical Information System (GIS) based Walkable Service Area Analysis (WSAA), a spatial network analysis technique. This destination density metrics method was used for the analysis in this thesis because this thesis aims to examine the factors that impact the built-in environment in Huntsville. In a high-potential small developing city like Huntsville, a built-in environment(destination density) weighs more than the street furniture. For improving the walkable condition in the USA, professionals need to measure the accessibility of the present walkability condition and improve policies and plans according to the accessibility measurement.[5]

In the second chapter, the literature review found that based on the research goal, data availability, considerable time and money, the WSAA method is more user-friendly than other methods. Therefore, this chapter includes a literature review according to the key research topics includes in this thesis.

The third chapter of the thesis is design and methodology. This chapter described how the objectives were accomplished by step-by-step analysis, assessment, and evaluation. First, using the WSAA method walkability score was measured based on destination density. The destination used in this method are places where people frequently visit, including retail uses(grocery stores), commuting destinations(schools, colleges, universities), recreation destination(park, theater, trailhead), social amenities(library, bus stop), emergency services(hospitals), financial institutions(banks and credit unions, post offices) and airport. A Standard walkable distance of one-quarter mile was used in this method. Next, the walkability scores of census tracts were generated by the WSAA method and using the calculated index. Consequently, the walkability analysis map was categorized into five parts based on walkability scores: not walkable (0), low walkable (1-20), medium walkable (21–40), high walkable (41–60), and exceptionally walkable (61–100). These parts were analyzed based on socio-demographic factors(median household income, population, and poverty) and land use cover.

Chapter four represents the description of the analysis results and identifies the most important factors for improving the walking environment in the city of Huntsville. Furthermore, this chapter analyzed the land cover for creating pedestrian-friendly environments in Huntsville. Finally, chapter five recommends the necessary potential improvements for initiating a pedestrian master plan in the city of Huntsville.

Statement of the Problem

US metropolitan gradually grew as a low development density, low densely populated, and automobile-dependent area as a result of various historical development[6]. Although early American cities were highly walkable with diverse and mixed uses, later after post-industrialization, high-speed, affordable transport changed the situation[5]. With the advancement of transportation technology, the walkability and pedestrian environment had debased day by day[7]. However, compared to the similar prospectus and developed Western European cities, US cities expanded more urban sprawl due to a lack of proper urban planning policies [8].

In the USA, only 9% of total trips were by foot compared to 39% in Sweden in 1990[5]. According to the US census bureau 2019, 1-year estimate data, around 75.9% of American people drive alone, around 8.9% carpooled, and only 5% of people use public transportation as their transportation mode to work. Moreover, the US census bureau 2019, 1years estimate data statistics show that almost all areas in the USA are auto-dependent without few big cities such as New York, Philadelphia, Boston, and Chicago. It is mentionable that Megacities like New York, San Francisco, Boston, and Philadelphia are very walkable[9]. After massive industrialization still, there are some towns walkable only because of high density, such as Boston [5]. For automobile dependency, people face many problems because it reduces economic productivity and development. Moreover, the pedestrian death rate is significantly high in automobile-dependent areas compare to less automobile-dependent areas [10]. A walkable city is important because it is beneficial for human health, social relations, and the natural environment [5].

Nowadays, one of the biggest concerns of the world is global warming. People often struggle for different natural and human-made disasters. There is no other way to reduce these environmental issues but to focus on environment-friendly transportation modes such as

walking, bicycling, and others. Unfortunately, it is almost impossible to convert these US cities from auto-oriented to environment-friendly transportation modes in a short time. To mitigate the different detrimental social, environmental, and economic effects of the urban sprawl of a fast-growing developing small city like Huntsville city, a proper urban planning policy or a master plan is necessary. Otherwise, when Huntsville converts to a more developed and densely populated city in the future, this city could face a hazardous situation.

However, A proper planning policy should concern socio-demographic and economic condition, environment, people health, and all other basic components of life. The smart growth approach mentions all the ten principles for a healthy, vibrant urban life. Among them, creating a walkable environment is one of the critical principles. Researchers often developed the walking environment by designing pedestrian-friendly road furniture, pedestrian pathway, and other street furniture. In maximum cases, a stronger built environment affects walking and physical activity for advantaged groups than for disadvantaged groups[11]. Hence, it is often noticeable in small auto-oriented US city like Huntsville that even if a beautiful landscape, pedestrian-friendly street furniture exists, it is hard to find someone walking there without recreational and health purposes. Unfortunately, there has been almost no research found to analyze the factors behind that.

In order to fill this knowledge gap, this thesis examines the factors and analyzes the lands that need to be focused on before making attractive pedestrian walkways in the city of Huntsville. This thesis helps build the step-by-step development strategy to initiate a pedestrian master plan. Furthermore, this thesis makes recommendations concerning socio-demographic factors, making the research highly significant because the relationship between walkable or supportive built environments might differ for different socioeconomic conditions [12].

Purpose and Objectives of the Study

The purpose of this study is to examine the factors that affect walkability and accessibility, develop an updated Walkability Service Area Analysis model, and finally recommend potential strategic actions concerning socioeconomic status(SES), population density, and land use of Huntsville City.

Hence, to reach this purpose of the study, the following specific objectives were performed:

1) Develop a Geographical Information System (GIS)-based model using destination density metrics.
2) Examine the reliability and validity of the GIS model with Street Smart Walk Score
3) Examine the relationship between GIS-model-generated walkability scores & socio-demographic factors and walkability score & land-use covers that affect walkability and accessibility.
4) Analyze the factors that affect walkability and make recommendations based on the analysis to guide the potential solutions to walkability problems in Huntsville, AL.

This thesis attempts to address the following questions:

Research question 1: What factors affect pedestrian accessibility, and how is the walking condition in the city of Huntsville measuring pedestrian accessibility?

Research question 2: What are the prioritized potential improvement areas in the city of Huntsville supported by social equity & efficiency standards?

In order to answer these research questions, this research is hypothesized that the highest densely populated area people have the highest walkability score [13]. On the other side, the area with the highest median household income has the lowest walkability score, assuming Huntsville as a small developing automobile-dependent city [14].

CHAPTER II

REVIEW OF LITERATURE

This chapter has divided into five parts. The first part briefly discusses the previous studies on walkability theory and its relation with different factors. The second part explains the preceding researches on walkability analysis with the help of Geographical Information System(GIS) software. The third part mentions researches that used online walk score and narrates the validation of this walk score from the preceding research works. The fourth part discusses the horizontal and vertical notion of spatial equity. Finally, in the fifth and last part, the notion of accessibility is reviewed from previous researches.

Walkability theory

For building a sustainable city, walkability is one of the most important foundations [7]. The definition of walkability varies between phenomena such as means or conditions(ex. road, street furniture), walkable environment, enhancing transportation options, or inducing exercise[15]. The term walkability can be discussed in different contexts such as environment, transportation, design, and walkability refers to making a walkable environment like certain areas traversable, compact, physically enticing, safe, and others[15]. Experts developed a conceptual framework that differentiates different concepts and definitions of walkability [15]. The notion of sidewalk access, street connectivity, and land-use density and diversity was examined to define walkability in contradiction with the pedestrian level of

service (LOS) measures[16]. Experts need to conduct more multidisciplinary research for developing a more advanced walkability matrix [16].

[5] described the importance of bicycling and walking in the current transportation planning. Bicycling and walking give travelers the option to select the mode of transportation [5]. Walkability increases the chance to reserve cultural resources and aesthetics [1]. Walking and walkability provide numerous benefits such as essential mobility, consumer cost savings, cost savings, efficient land use, community livability, improved fitness and public health, economic development, and support for equity objectives[1]. One of the benefits of walking and bicycling is that walking and bicycling are socially equitable and beneficial for physically, economically, and socially disadvantaged people [1]. There are three kinds of benefits for walking: economic benefits, social benefits, and environmental benefits [1]. The external expense of motorized vehicles is far higher than walking such as external cost factors such as crashes, parking, traffic congestion, roadway facilities, roadway land value, municipal services, air pollution, noise, resource externalities, barrier effects, land use impacts, water pollution, and waste disposal [1]. Furthermore, experts pictured economic, social, and environmental land use benefits of walkability[1]. For environmental benefits, the specialist added that walking behavior reduces energy consumption and pollutions[1]. Walking can especially increase the accessibilities of pedestrians and hence reduce the transportation cost. Walking helps to increase social interactions and community cohesion. Besides, walkable neighborhoods could develop economic conditions in a neighborhood.

The detrimental health effect of walkability is obesity in developed counties, especially in the USA [16]. Obesity rates in the USA increase day by day due to less physical activity, and one-third of adults in the USA are affected by obesity[16]. Researchers are concerned about health damages that occur due to physical inactivity because health and obesity also impact the economy[16]. Human bodies could be affected by diseases like heart

disease, hypertension, stroke, diabetes, obesity, osteoporosis, depression and dementia, and some types of cancer[17]. Moreover, [17] described different health benefits of increasing walkability. Many studies were done in the field of urban planning to identify the characteristics of the built environment associated with active transportation physical activity and related health outcomes, such as lower rates of obesity, cardiovascular disease, diabetes, and stroke[17]. Physical activity is strongly affected by neighborhood walkability[18]. Therefore, public health can be increased by improving the walking rates ([19], [20], [21]). The walking, bicycling, and transit-friendly environment are predictive of more walking or physical activity ([22], [23], [24], [25], [26]).

Researchers discussed pedestrian needs focusing on the performance dimension and criteria for a walkable city, especially for the urban and suburban environments [5]. [5] described the influence of a better pedestrian environment for people to choose walking over driving. Still, the federal expenditures on the development of walking and bicycling are trivial than the expenses on an automobile by 1:1000[5]. The criteria for walkable cities were briefly delineated, which are connected, linkage with other modes, fine-grained and varied land-use patterns, safety, path quality, and path context [5].

Especially the high-speed traffic had broken the pedestrian-friendly environment [7]. Roadside infrastructure improvements increase walking and physical activity [27]. The walking environment impacts walking behavior according to the age group and population size [28]. Neighborhood socioeconomic conditions also impact this relation. The key elements of making walkability in a neighborhood are greater density, more land use mix, and higher connectivity [24]. High walkability directly positively impacted walking for transport, leisure-time physical activity, and accelerometer-based moderate-to-vigorous physical activity[29].

There is a strong positive relation between walkability and active transportation [30]. The relationship between neighborhood socioeconomic status (SES) and walkability is still contradictory [30]. Neighborhood SES has no strong impact on the relationship between walkability and physical activity [31]. Experts studied characteristics or attributes that could increase walkability via people's perceptions [32]. The proximity of destinations, good weather conditions, safety, and well-designed pedestrian facilities are the main positive influencer of increasing walkability [32].

On the other hand, Improving the walkable environment did not encourage people to walk more if people have negative perceptions of neighborhood safety [33]. The network design impacts the pedestrian walk because network design helps pedestrians determine which way is shorter and convenient to reach their destination [34]. Grid networks with short blocks are convenient for pedestrians [34]. Not only grid networks and sidewalks important for walkability, but also setbacks and parking are vital [34]. Land-use mix, residential density, and street connectivity are the root components for increasing walkability [35]. Moreover, higher population density, greater connectedness of streets, and mixed land use greatly impact walking behavior and bicycling trips [24]. However, experts pointed out that population density and pedestrian infrastructure increase walking rates [36]. Moreover, the weather condition, precipitation, average temperature affects the walking rate [36]. Some researchers stated that walkability depends on road conditions [15]. In contrast, others explained that making places lively and vibrant, enhancing transportation options, or inducing exercise makes a suitable walking environment[15].

Walkability indices are strongly positively correlated with walking trips for most non-work trip purposes [37]. However, for every individual or household, a walkability index would not have the same correlation with travel behavior [37]. The authors used four commonly used walkability indices for the analysis: walk Score, Walk opportunities,

Walkability index, and pedshed connectivity [37]. A high-walkable neighborhood increased the walking for transport among the peoples[31]. The authors also stated that this relationship is stronger in high SOS(socioeconomic status) [31]. But in the case of the Neighborhood Quality of Life Study (NQLS), researchers did not find any interrelationship of SOS between the quality of life and neighborhood walkability[29].

Walkability Analysis Approach with GIS

The Geographical Information System (GIS) based Walkable Service Area Analysis (WSAA) methodology was first applied in Washington, DC for measuring walkability based on the density of walkable destinations using network distance[38]. The project used Census blocks and block groups to demonstrate the walkability scores in Washington, DC. The project selected this method because interview and site surveys are sometimes needed considerable time and cost[38]. However, using destination density and network connectivity methods are preferred nowadays because data is available and cost-effective[38]. For the project, 18 types of destination points were selected where residents are most frequently visited, such as grocery stores, shopping, community gardens, restaurants, theaters, libraries, post offices, banks, medical care, elementary schools, middle schools, high schools, universities, workplaces, neighborhood parks, recreation facilities, bus stops, and metro station. However, standard walking distances (400 or 800 meters) and weights were assigned according to the trip frequency and importance of the points. After creating a distance buffer using the road network of Washington DC using the spatial analyst feature in GIS, a walkability raster surface was made. Then, a raster calculator was used to multiply each factor's input raster by the assigned weight. Finally, using zonal statistics in Spatial Analyst, the generated walkability scores were aggregated by census block. The census block was

used for analysis because all the statistical data is available in the census dataset. However, it is easier to compare walkability to demographics or any other census dataset [38].

Edrine city of Turkey was evaluated by the same approach (Walkable Service Area Analysis)[4]. The research aims to identify low walkable areas and measure walkability scores in Edrine City[4]. The environment in Edrine city is suitable for walking because of the topographical condition[4]. The author followed Walkable Service Area Analysis (WSAA) methodology to determine the walkability scores of neighborhoods of the city of Edirne in Turkey[4]. The network distance methodology was used for the research because of original data obtained was available by a physical survey of local authorities and planning companies. Furthermore, the author classified the walkability scores into five categories: not walkable, low walkable, medium walkable, high walkable, and exceptionally walkable[4]. 11 points of destination was collected for the study, such as public destination (primary education, social center, and university), recreation areas (parks and kinder garden), transportation points (public transportation stops), commercial areas, and hospitals. However, distance values (400 and 800 m) and the Value of weights between 1 to 14 were assigned to these destinations. Therefore, neighborhoods were used as spatial units to demonstrate the walkability scores in Edrine City[4].

[16] combined six parameters to measure walkability in New York City (NYC). These six parameters are residential Density, Diversity-Entropy Index, Connectivity, Proximity, Environmental Friendliness, and Commercial Density-Retail Floor Area Ratio (FAR). All obtained walkability scores were aggregated and weighted again using the Geographical Information System (GIS). Finally, the author developed an updated walkability index to combine these six parameters[16].

Validation of Walk Score

Street Smart Walk Score generates a walk score for each address by calculating the walking distance to 9 different categories of amenities[39]. Then, these categories are weighted according to their determined significance level. This methodology also counts the average block length, or intersection density also counts for impacting the walkability. Moreover, the Street Smart Walk Score calculated the distance from the following destinations: grocery, restaurants, shopping, coffee, banks, parks, schools, books, and entertainment[39].

Walk Score is recently recognized as a novel, valid, reliable, and publicly available website for measuring accessibility to nearby locations([40], [41]). The authors examined the relationship between Walk Score and walkability factors(street connectivity, residential density, and access to public transit provisions)[40]. There are significant positive correlations between walk score and walkability factors, suggesting that Walk Score is a convenient tool for measuring neighborhood density and access to nearby amenities[40]. Later, the validity and reliability of the Smart Street Walk Score were examined for measuring accessibility to walkable amenities [41]. Again, the authors found significant relations and commented that Walk Score is a reliable and valid measurement tool [41].

Walk Score is valid for measuring walkability differentiate on certain distance and area [42]. The authors found that longer buffer areas(1600 m) have more validity than shorter buffer areas(400 m) [42]. Furthermore, higher density areas have more walk score validation than low-density areas[42]. Experts examined the relationships between Street Smart Walk Score and Transit Score[43]. They found that low walk score areas encourage transport walking, but high transit score supports leisure walking[43]. Score and Transit Score are both beneficial for measuring neighborhood walkability[43]. Hall & Ram(2018) 42 journal articles relevant to Smart Street Walk Score were reviewed and evaluated[44]. The

authors stated that 29 research papers among the 42 journal articles use Walk Score as a supplementary source besides other methods for measuring walkability, and 33 research works use Walk Score® as an independent variable but never used it as a dependent variable[44]. The result supports that Walk Score® is only used to measure the density of the built environment that facilitates utilitarian walking potential[44].

Notion of spatial equity

This section discusses two different kinds of spatial equity notions: horizontal spatial equity and vertical spatial equity.

Horizontal spatial equity: Horizontal spatial equity refers to the equal distribution of facilities for the residents no matter where they live or their socioeconomic condition([45], [46]). Horizontal equity refers to distribution among residents with the same demand[47]. Social transportation equity equivalently increases the overall costs[47]. The costs of the system vary according to the achieved level of equity[48]. A study examined the horizontal spatial equity with different green spaces and found that education, age groups, and population density are important factors for accessibility to green spaces.[49]

Vertical Spatial Equity: Vertical spatial equity means equitable distribution of facilities with regard to the location and demand of the residents ([50], [51]). Vertical equity refers to distribution among residents in situations with different levels of necessities[47]. The vertical equity with different social groups was examined, and experts noticed that females, residents with low education, children, the elder had unequal accessibility, and the migrants had unequal access to green spaces [49].

The notion of accessibility

A research study measured the spatial accessibility to primary care physicians and found that those places that lack health professionals are low access to primary care physicians [52]. Again, Researchers applied GIS-Based methods of measuring spatial accessibility to health services in Chicago [53]. The authors compared two GIS methods and found a significant difference between the two models[53]. One study suggests focusing on more improvement on these methodologies based on the radius of the service area, type of provider, or the type of neighborhood[54]. Experts developed a model for measuring spatial accessibility to parks [55]. The authors found that by this population-weighted distance (PWD) model, US residential populations are predicted to travel 6.7 miles to access their local neighborhood parks, and it significantly varies for different regions. African American neighborhood constantly loses its accessibility to the nearest supermarket and is average 1.1 miles less proximate than white neighborhoods [56]. Another study discussed the concepts, methods, and challenges of spatial accessibility of primary care [57]. The author found that the most popular method for measuring accessibility travel impedance to nearest provider and supply level within bordered areas was invalid for congested urban areas [57].

CHAPTER III

DESIGN AND METHODOLOGY

This study was conducted by a five phases strategic method. Each phase was performed to accomplish the objectives of the study. In the first phase, the Researcher collected the different interest points where people in Huntsville frequently visit, such as grocery stores, schools, hospitals, universities, colleges, bus stops, parks, banks and credit unions, post offices, theaters, libraries, and libraries, trailhead, and airport. These data were collected from the City of Huntsville website, United States Census Bureau, google earth, and ESRI website. Then a network dataset in Arc Catalog was created. Therefore, relevant walking distances and relative weights to the factors were assigned. Afterward, network distance buffers around points for each factor were generated and converted to raster network distance buffer features. Then, Raster Calculator in Spatial Analyst was used to multiply each factor's input raster by the assigned weight for that factor and sums the results. The resulting walkability density surface is the main walkability score map. Finally, the census tract areas were categorized into five classes according to walkability scores. These categories are not walkable (0), low walkable (1-20), medium walkable (21–40), high walkable (41–60), and exceptionally walkable (61–100).

In the second phase, the author conducts an online walkability audit. The average walk score of every road in Huntsville city was collected from https://www.walkscore.com/. Therefore the average walk score of every census tract in Huntsville was calculated with the

help of GIS and MS Excel. To examine the validity and reliability of WSAA generated walkability score, z test: two sample for means was performed by MS excel.

The third phase demonstrates the relationship between WSAA generated walkability score and socio-demographic factors(population density, median household income, and poverty percentage). Therefore, the relationship between land use covers and walkability was examined. A bivariate correlation method was applied to examine these relationships.

The fourth phase is described in chapter four, aiming to identify and analyze the factors that affect walkability in Huntsville. The fifth and final phases are described in chapter five. This phase makes recommendations based on the identification and analysis of phase four. This chapter summarizes all of the steps of the first three phases to reach the goal of the study.

Study Area

The study area is Huntsville, which is on the northern side of Alabama, in the United States of America. Huntsville has an area of 215.73 sq. mi and a population of 180,105.

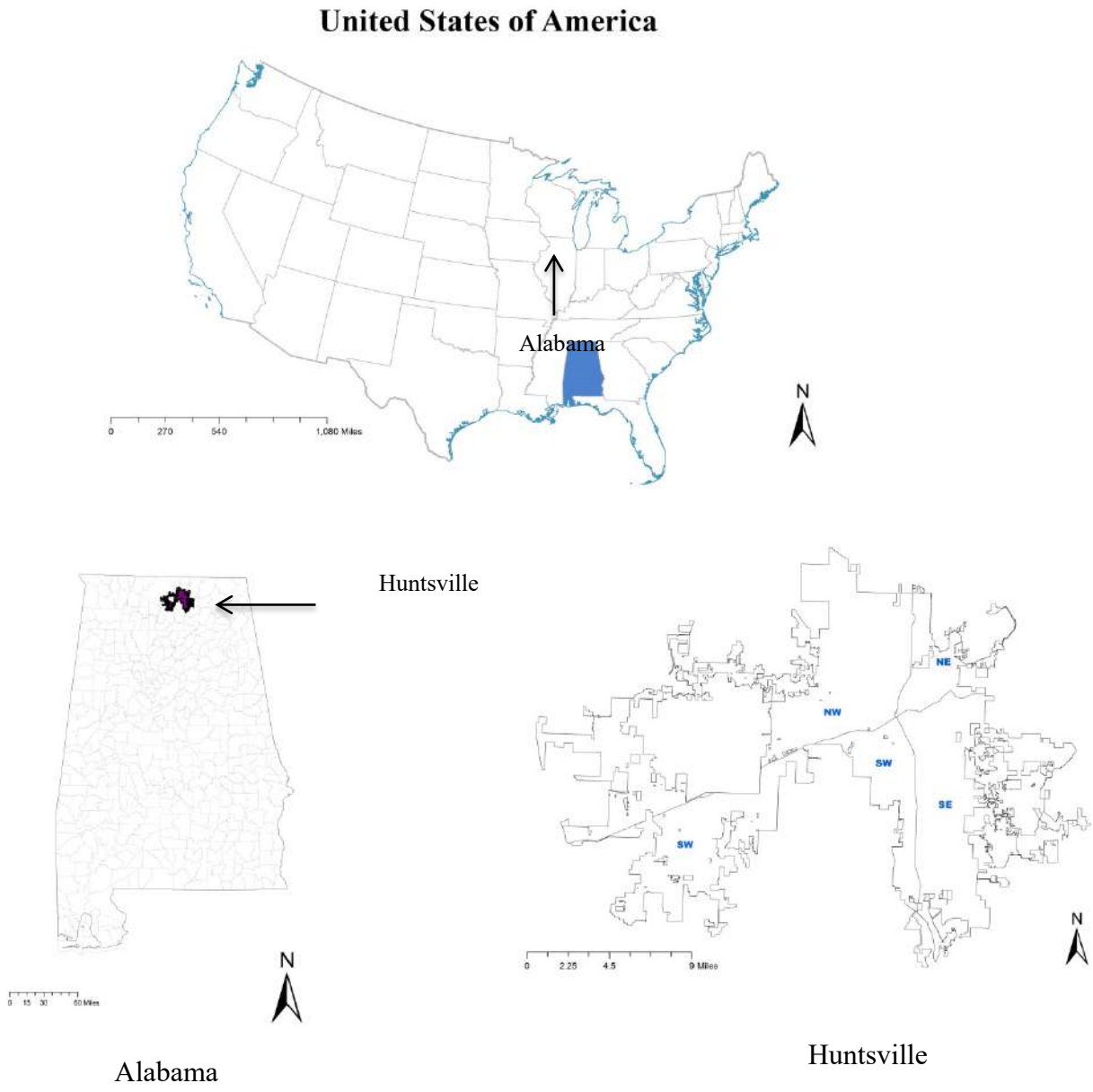


Figure 1: Study Area

Develop an updated GIS model

Sample Description: The data used for Walkability Service Area Analysis (WSAA) was collected from different sources summarized in the following table.

Web addresses:

1. https://www.huntsvilleal.gov/
2. https://www.census.gov/en.html
3. http://www.esri.com/data/download/census2000-tigerline/

Soft wares:

1. Google Earth Pro
2. Geographical Information System(GIS)

Table 1: Data Sources of GIS data layers used for Creating WSAA Map

Data Layer	Use in Project	Source(see above)	Currency
HuntsvilleMadison_County_E911 _Center_Road_Centerlines	Network Dataset	City of Huntsville GIS Open Data	2020
Huntsville City Boundary	Study Area Boundary	City of Huntsville GIS Open Data	2020
Grocery Stores	Destination(Grocery Stores)	Google Earth Pro	2019
School	Destination (Schools)	City of Huntsville GIS Open Data	2017
Hospital	Destination (Hospital)	Google Earth Pro	2019
University	Destination (Universities)	Google Earth Pro	2019
College	Destination (Colleges)	Google Earth Pro	2019
Bus Stop	Destination (Bus Stops)	Google Earth Pro	2019
Park	Destination (Parks)	City of Huntsville GIS Open Data	2019
Banks and Credit Unions	Destination (Banks and Credit Unions)	Google Earth Pro	2019
Post Office	Destination (Post Office)	Google Earth Pro	2019
Theater	Destination (Theater)	Google Earth Pro	2019
Library	Destination (Library)	City of Huntsville GIS Open Data	2019

Trailhead	Destination (Trailhead)	City of Huntsville GIS Open Data	2017
Airport	Destination (Airport)	City of Huntsville GIS Open Data	2017
Census 2010 Tracts	Spatial Units	City of Huntsville GIS Open Data	2010

Creating WSAA Map: This paper use 13 basic destination services where people regularly make transportation trips. Assign comfortable standard walking distance for each destination service and allocate weights based on the assumption of the usage of these destination services in Huntsville city. [38] and [58] were followed for selecting distance standards of destination points. The following weights are selected based on the preceding walkability research. It has been proved that grocery stores, grocery stores, restaurants/bars, banks, and schools increase walking trips ([23] [59]). Grocery stores, restaurants/bars, retail locations, coffee shops, and banks are frequent walking destinations [60]. Not only that, people regularly walk to parks for recreation purposes[60]. Experts pointed out grocery shops should have the highest weight because it has been found that grocery shops are the drivers of walking to the destinations[23].

Table 2: Walking distances and weights for the Selected Destination Points

Destination	Distance(m)	Weight
Grocery	400	25
Schools	400	15
Hospital	800	10
University	800	8
College	800	8
Bus Stop	400	6
Park	800	6
Banks and Credit Unions	800	5
Post Office	800	5
Theater	800	4
Library	800	3
Trailhead	800	4
Airport	800	1

In Arc Map, all destination data points and road centerlines of Huntsville-Madison County were added. Afterward, by Arc Catalog, a network dataset of these road centerlines was created. In the next step, 400 or 800 meters of standard network distance buffer polygons was created using the service area function in the network analyst toolbar around each destination point. After opening the network analyst window, loaded destination points as the facilities. From the layer properties in the network analyst window, using selected network distance 400 or 800 meters as default network distance generates polygon using the merge by break value as well as uncheck trim polygons. Then, a new field was added in the attribute table named 'Value' to the Huntsville boundary polygon and assigned it a value of 0. After that, unions of Huntsville boundary polygon and each generated service area polygon were made. By field calculator, assigned 1 to the generated service area polygon. These union polygons converted to raster using Spatial Analyst based on the new field of the attribute table 'Value.' In the last step, multiply each service raster by the assigned guessed weight and summarize in the raster calculator. The resulting walkability analysis map is the final output map.

Walkable Service Areas measured for Groceries and Schools respectively for example

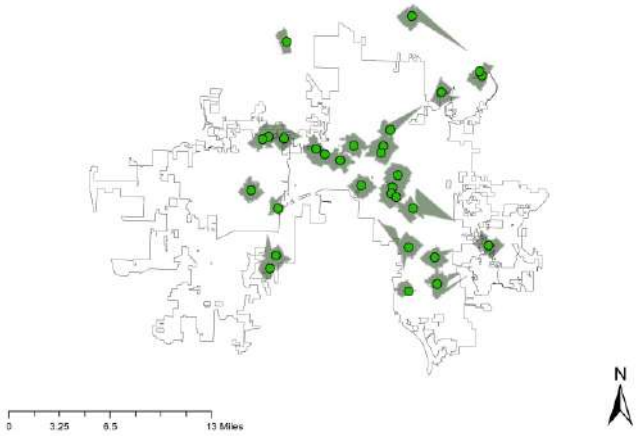


Figure 3: Walkable Service Areas measured for Schools

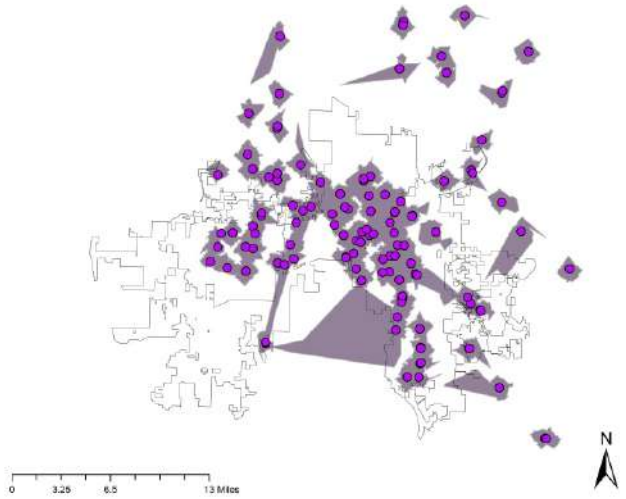


Figure 2: Walkable Service Areas measured for Groceries

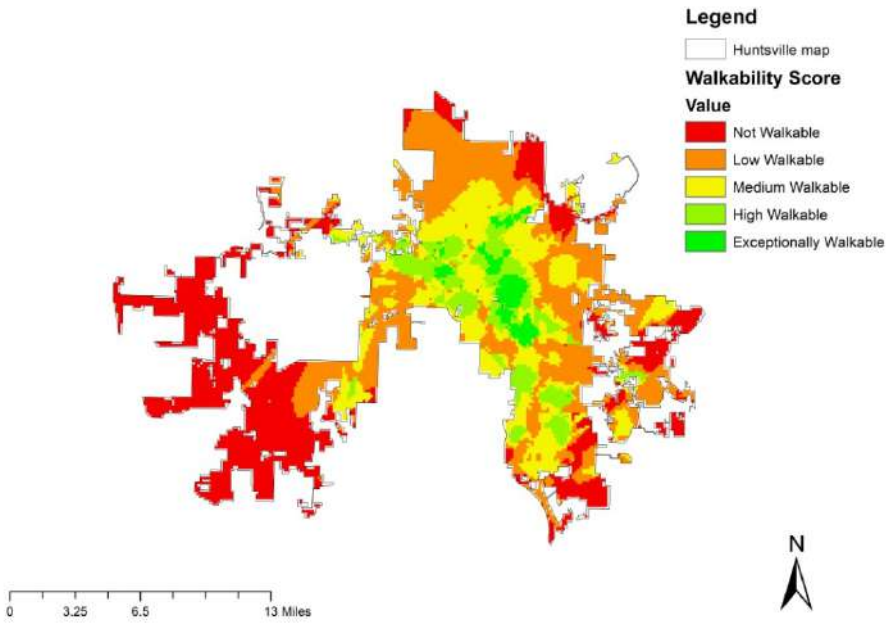


Figure 4: Walkability Score Map of Huntsville City

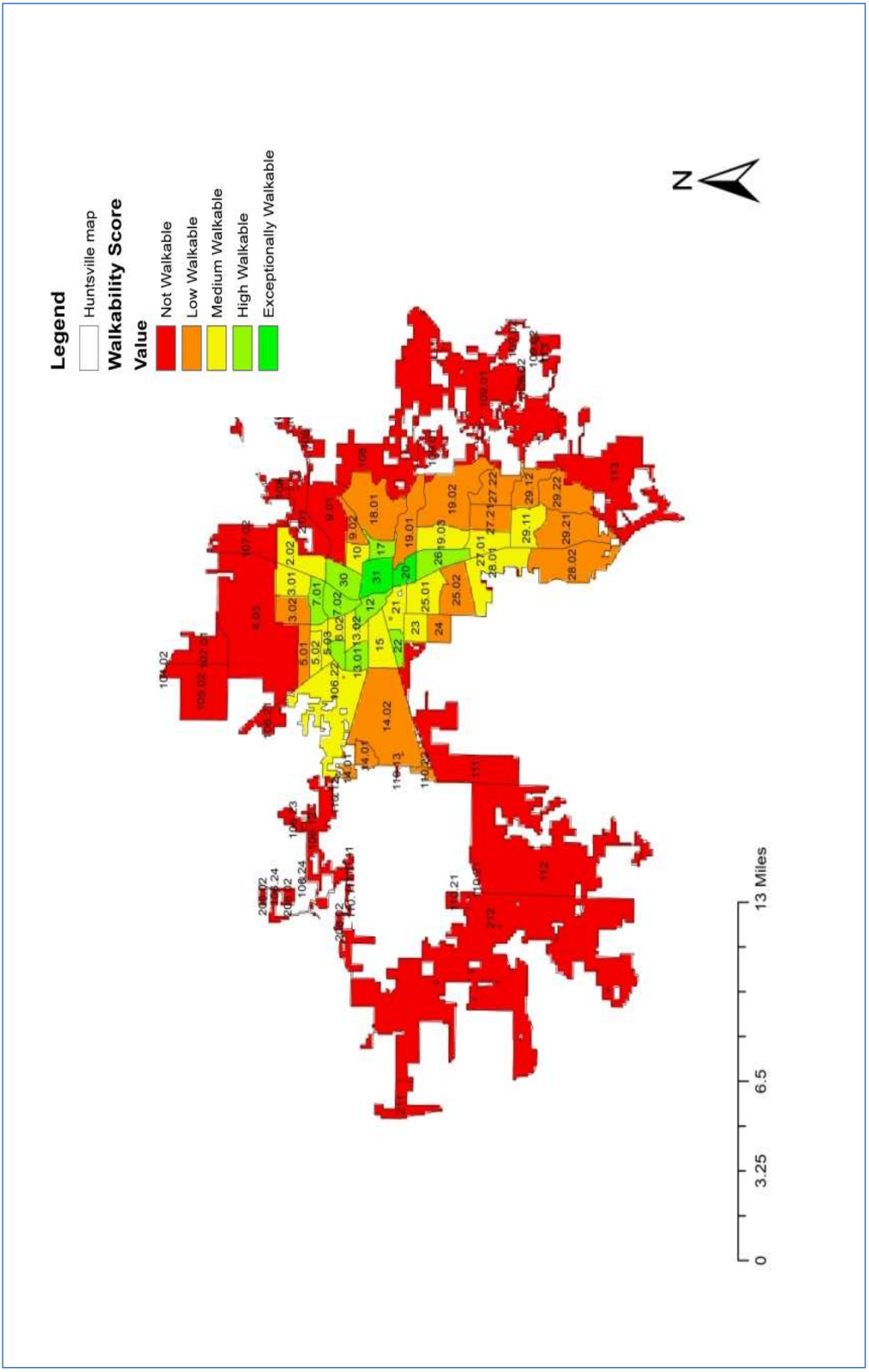


Figure 5: Walkability Score Map by census tracts of Huntsville City

Validation of WSAA Score

The Researcher extracted the mean Walk Score® of every road in Huntsville from www.walkscore.com. The website measures the walkability scores by using their patented system. For each road, they calculated points based on the distance to all categories of amenities. Same as the WSAA method, they used 0.25 miles(400 m) or 5 minutes walking distance for full credit points. After 0.25 miles, more distance is credited for lesser points. They assigned points up to 30 minutes walk or 1.5 miles and amenities distance more than 1.5 miles assigned no points.

The mean walk score of all roads was collected for 64 census tracts of Huntsville. For mitigating the measures of error; mean Walk Score® of roads above 5 miles, major highways, major access, and road ramps were not counted. The Walk Score® of these roads is significantly different for distance points because these roads are longer. Hence, these roads are not statistically significant for this study. 14 roads within Huntsville are identified for length more than 5 miles

Table 3: Roads within Huntsville: length more than 5 miles

No	Road Name	Length(miles)
1	AL 20 HWY NW	12.277629
2	AL 53 HWY NW	5.305757
3	BAILEY COVE RD SE	5.339259
4	INTERSTATE 565	37.029593
5	INTERSTATE 65	6.591969
6	MEMORIAL PKY NW	21.964196
7	MEMORIAL PKY SW	33.391939
8	MERIDIAN ST NE	6.029948
9	PULASKI PKE NW	10.046158
10	RESEARCH PARK BLV NW	14.617594
11	SPARKMAN DR NW	6.692291
12	UNIVERSITY DR NW	8.831813
13	US 72 E HWY NW	10.791995
14	WHITESBURG DR SE	5.055046

All calculated mean Walk Score® and WSAA generated walkability score of 64 census tracts in the city of Huntsville is attached in Appendix A. Therefore, a Z-test was conducted to compare the two data models because the sample size is 64, which is more than 30.

The result of the Z test of Walk Score® And WSAA Generated Walkability Score is shown in the following table(see Appendix A):

Table 4: Z-Test: WSAA generated walkability score and Walk Score®

	WSAA	*Walk Score®*
Mean	26.08496904	22.07453619
Known Variance	286.6523758	282.9897364
Observations	64	64
Hypothesized Mean Difference	0	
Z	1.344250454	
P(Z<=z) one-tail	0.089433706	
z Critical one-tail	1.644853627	
P(Z<=z) two-tail	0.178867411	
z Critical two-tail	1.959963985	

The result shows that P=0.089 means there is no significant difference between these two sets of data. Thus, the result suggests that the WSAA model is reliable and valid for this study.

Analyzing Socio-demographic factors and land use cover with walkability

Three categories of socio-demographic data(population density, median household income, and percentage of poverty) have been extracted from census tract 2010. These data are attached to Appendix B. Therefore, the land use cover map of Huntsville was extracted from USGS. Furthermore, the majority of the land cover of every census tract has been calculated with the help of GIS. Finally, a bivariate correlation method was applied to examine the relationships between walkability score & socio-demographic factors and walkability score & land use cover.

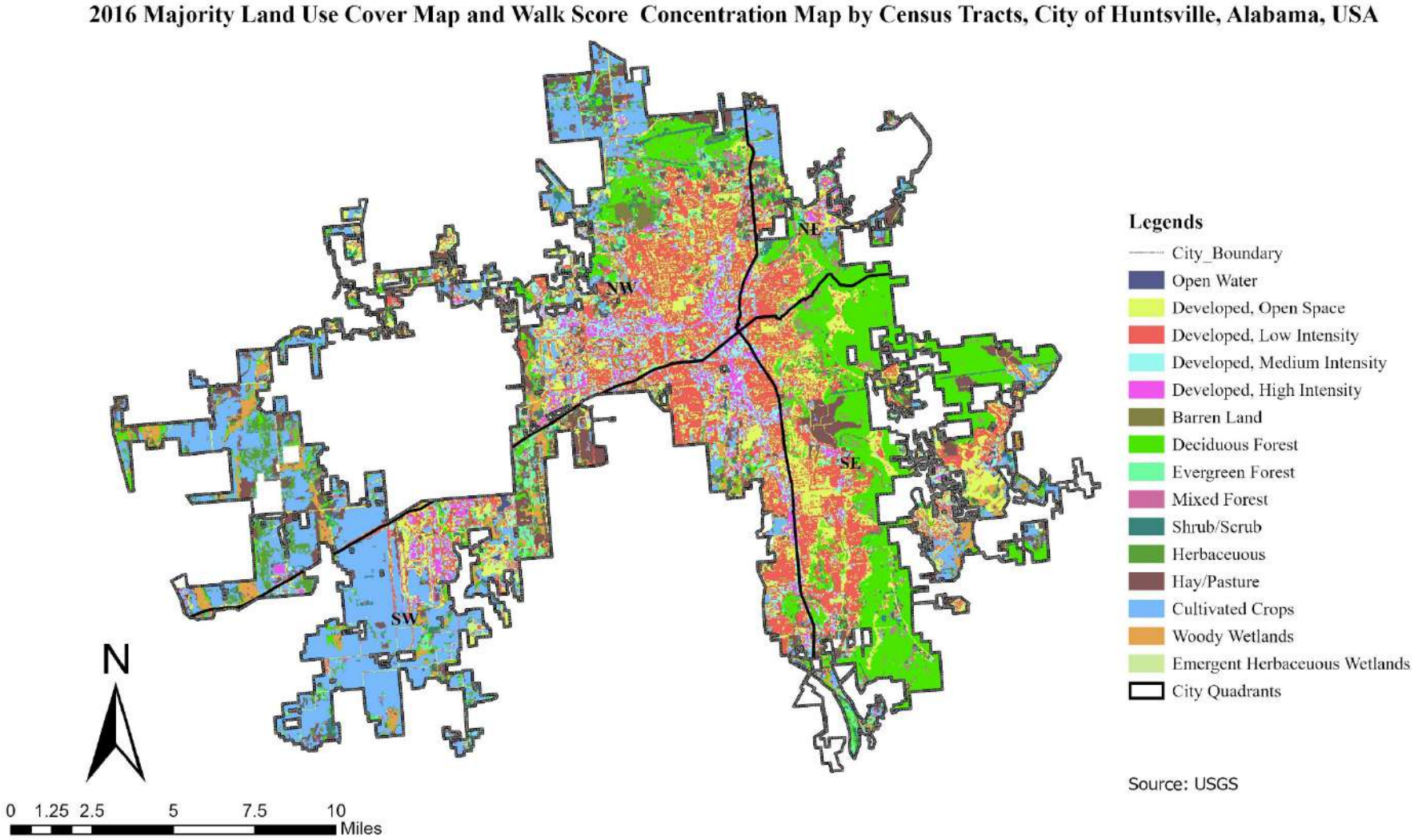


Figure 6: 2016 Land Use Cover Map of City of Huntsville, Alabama

The following table is generated from the 2016 Land Use Cover Map of Huntsville

Table 5: Land use cover of Huntsville City

Value	Land_Cover	Areas(Square Miles)	Percentage of Areas
11	Open Water	1.3864851	0.633387437
21	Developed, Open Space	31.84572105	14.54806809
22	Developed, Low Intensity	39.74486373	18.1566303
23	Developed, Medium Intensity	13.58512155	6.206085678
24	Developed, High Intensity	5.54107554	2.531327337
31	Barren Land	0.76517298	0.349553668
41	Deciduous Forest	37.11471192	16.9550991
42	Evergreen Forest	4.34258253	1.983820251
43	Mixed Forest	4.24493784	1.939213266
52	Shrub/Scrub	6.9914988	3.193923618
71	Herbaceuous	5.08933854	2.324960503
81	Hay/Pasture	17.6455422	8.06100603
82	Cultivated Crops	39.88663965	18.22139774
90	Woody Wetlands	6.38999361	2.919138241
95	Emergent Herbaceous Wetlands	0.28702674	0.131122312
Missing Data	N/A	4.03928822	1.845266432
Total		**218.9**	**100**

From Figure 6, the majority of land covered by 64 census tracts in Huntsville was calculated. Figure 6 shows the majority land use cover map with walkability scores. land use covers are coded with numerical numbers for bivariate correlation.

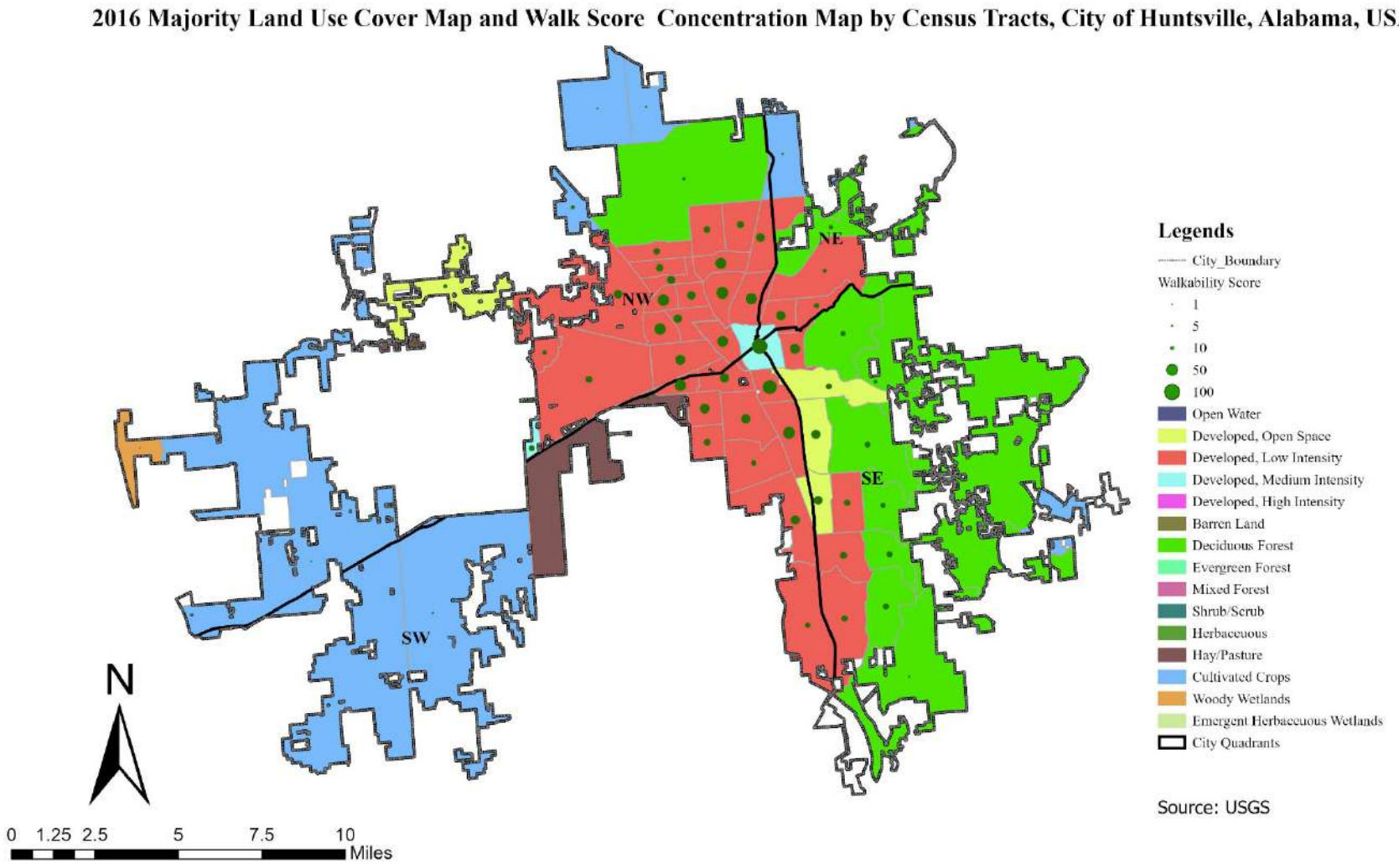


Figure 7: 2016 Majority Land Use Cover Map and Walk Score Concentration Map by Census Tracts, City of Huntsville, Alabama, USA

The following table is generated from Figure 7,

Table 6: Majority land cover by the total number of census tracts

Majority Land Cover	Number of census tracts cover
Developed, Low Intensity	35
Deciduous Forest	11
Cultivated Crops	8
Developed, Open Space	5
Developed, Medium Intensity	2
Hay/Pasture	2
Woody Wetlands	1
Total	64

CHAPTER IV

RESULTS AND DISCUSSION

Chapter Four is divided into three parts. The first part shows the analysis of different factors with walkability scores, the second part describes the results of the analysis, and the third part briefly discusses the interpretation and analysis of the result.

Analysis of Walkability Factors

Table 7: Descriptive Statistics of walkability score and walkability factors

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Walkability Score	64	.00	70.02	26.0850	16.93081
Population Per Square Mile	64	30.28	5085.76	1699.3807	1178.74008
Poverty Percentage	64	.60	64.70	17.8219	15.87643
Median Household Income	64	13918.00	109643.00	52984.2344	23589.49709
Land Use Cover	64	1.00	7.00	2.4531	1.78112
Valid N (listwise)	64				

Table 8: Bivariate Correlation of Walkability score and walkability factors

Correlations

		Walkability Score	Population per Square Mile	Median Household Income	Poverty Percentage	Land Cover
Walkability Score	Pearson Correlation	1	.676**	-.386**	.518**	-.733**
	Sig. (2-tailed)		.000	.002	.000	.000
	N	64	64	64	64	64
Population Per Square Mile	Pearson Correlation	.676**	1	-.358**	.527**	-.688**
	Sig. (2-tailed)	.000		.004	.000	.000
	N	64	64	64	64	64
Median Household Income	Pearson Correlation	-.386**	-.358**	1	-.794**	.442**
	Sig. (2-tailed)	.002	.004		.000	.000
	N	64	64	64	64	64
Poverty Percentage	Pearson Correlation	.518**	.527**	-.794**	1	-.527**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	64	64	64	64	64
Land Use Cover	Pearson Correlation	-.733**	-.688**	.442**	-.527**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	64	64	64	64	64

**. Correlation is significant at the 0.01 level (2-tailed).

From the above Bivariate Correlation method(Table 8), it can be said that the walkability score significantly correlates with all other factors($p<0.05$). Furthermore, these factors also significantly inter-correlated with each other. Walkability has a strong positive correlation with populations per square mile and poverty percentage. On the other hand, walkability has a medium negative correlation with median household income.

Land use covers are coded with numerical numbers for bivariate correlation.

Code	Land Cover Use
01	Developed, Low Intensity
02	Developed, Medium Intensity
03	Developed, Open Space
04	Deciduous Forest
05	Cultivated Crops
06	Hay/Pasture
07	Woody Wetlands

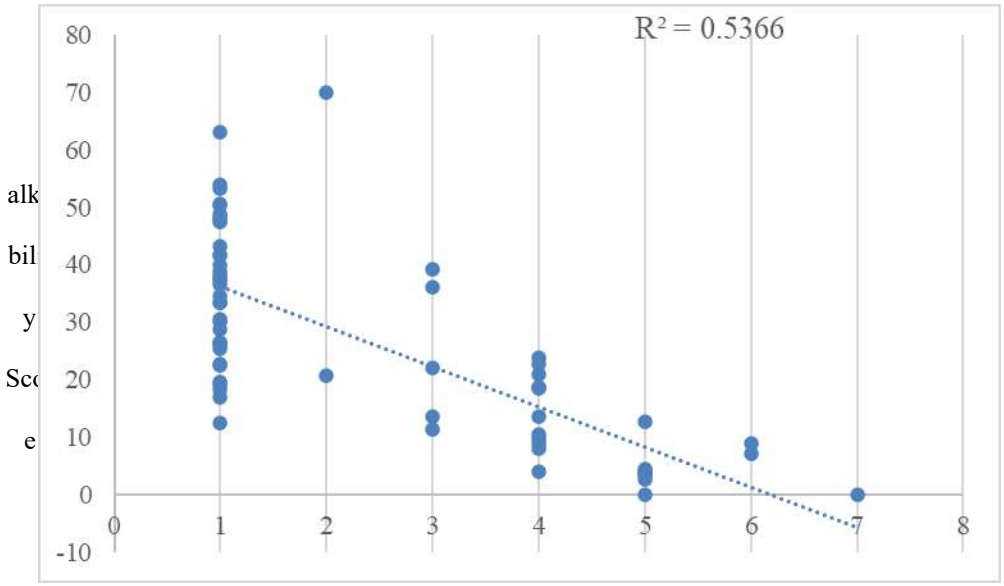


Figure 8: Scatter plot and regression Line of Walkability Score and Land Cover Use

Figure 8 shows a strong positive relationship between the intensity of the development and walkability score. The land cover uses were first coded with numbers one to seven, and then a scatter plot was generated to examine the land cover use tend with walkability score.

Results - Walkability Factors Analysis

From the analysis, it can be said that population density, Median Household Income, Poverty Percentage, land cover, and walkability score are significantly correlated with each other. The analysis reveals that high population density areas have more walkability scores than less populated areas. In other words, higher population density tends to increase walkability. On the other hand, low population density areas have lower walkability scores. Moreover, low poverty percentage areas tend to be highly walkable, which is significantly related to the median household income. But, notably, the correlation between median household income and walkability score is not as strong as other factors.

Regarding the inter-correlation of other factors, it is noticeable that population density is strong and positively correlated with poverty percentage. In other words, highly dense populated areas have more poverty percentages than low, dense populated areas. Poverty percentage increase with the population density increases.

Also, it is expected that median household income has a strong negative correlation with the poverty rate. High median household income areas have low poverty rates. Moreover, population density has a medium negative correlation with median household income. As population density decreases, median household income tends to increase in those areas.

Walkability and population density both have a medium negative correlation with median household income. In high walkable or high population density areas tend to decrease median household income. However, as these areas are mostly commercial and industrialized, low-income people also live in these areas. Thus, the relationship between median household income and walkability or population density is not strong.

In the case of land use, the medium-intensity developed land has the highest walkability score. Gradually, the walkability score drops, with the intensity of development decreases. For example, cultivated cropland, Woody wetlands, and Hay/Pasture lands tend to decrease the walkability score because of the very low-density population and low-intensity development. In Huntsville, there are other categories of areas such as developed Open Space and deciduous forest. These categories of land-use cover tend to have a medium to low walkability score respectively.

Review of Impacts of Walkability Factors in Huntsville

The low and medium area covers 33.41% and 22.008% area respectively. Table 8 demonstrates a significant correlation between walkability score and socio-demographic factors. Moreover, Table 8 says, Population density has positive impacts on walkability in Huntsville. Exceptional walkable areas have a low poverty rate because these places are the most commercially industrialized areas of the city. High and low SOS, both categories of people live in commercial and industrialized developed areas, although higher-income people tend to live than lower-income people. Thus, a moderate positive correlation between the average poverty percentage & mean walk Score. From Figure 5, the following table has been created with the help of GIS.

Table 9: Classified Walkability Score Areas

Class of Walkability	Area(Square Miles)	Percentage (%)
Not Walkable	61.728119	31.406887
Low	65.67094	33.412971
Medium	43.256796	22.008792
High	19.529143	9.936308
Exceptionally high	6.358258	3.235043

Table 9 shows that not walkable and low walkable area covers 64.82% of the total area, and only 13.17% are high walkable areas. It is mentionable that 31.41% of areas in Huntsville are almost not walkable. For example, census tract 211 and 212. There is no public transit and no amenities there. Hence, the development in Huntsville is not balanced. For making Huntsville more walkable, professionals should first focus on mixed-use development. It is unavoidable that mixed-use development automatically creates a walking environment

Census Tract 212

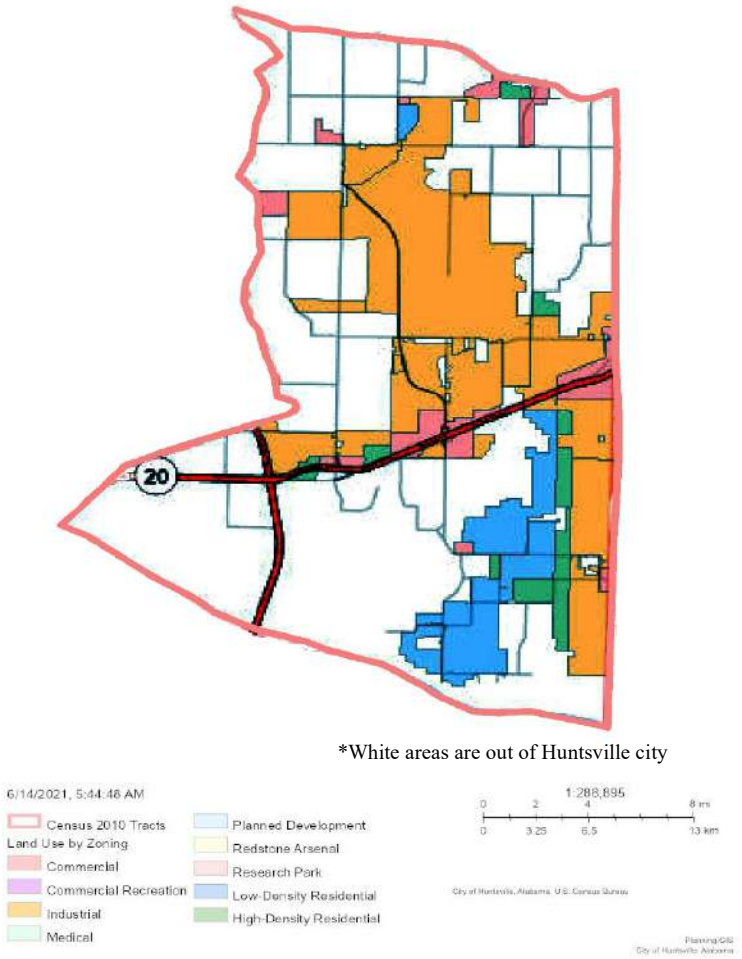


Figure 9: Land Use by Zoning Interactive Map of Census Tract 212

The above Figure 9 shows that CT 212 covers mostly industrial areas (commercial industrial park, planned industry and a tiny portion highway business C-4). Only a little part of CT 212 covers low-density residential. The majority of the CT 212 lands cover cultivated croplands which are low-density residential, commercial industrial park and planned industry. Similarly, majority of the areas in SW Huntsville cover cultivated croplands and are low walkable because of the lack of amenities and mixed-use development. The following table shows walkability scores, population density, and socioeconomic factors of eight census tracts that are covered by cultivated croplands.

Table 10: Walkability scores, population density, and socioeconomic factors of census tracts that are covered by cultivated croplands

Census Tract	Walkability Score	Population density (pop/square miles)	Median Household Income	Poverty Percentage
106.21	12.74	786.48	101474	2.6
208.02	4.5	373.12	59976	3.6
112	4.23	265.76	62643	6.9
107.02	3.58	524.38	54765	14.6
109.02	3.57	95.41	37578	17.6
107.01	3.54	229.80	57370	7.1
105.02	2.64	189.93	54506	18.3

Table 10 shows that all census tracts that covers majority of croplands have a very low walkability score and low population density, but most of these CTs have high median household come.

CT 211 has only a commercial area, and the majority of the land covers woody wetlands. The part of CT 211 fall in Huntsville are commercial (highway business C-4 zone). Notable, CT 211 and 212 have very low poverty percentage rates (only 10% and 9.8%, respectively) and low population density(92.60 and 72.06 per square mile). These areas have a very high median household income ($48420 & $38633, respectively).

From Figure 8, it is noticeable that only two areas in the Huntsville area are medium intensity developed areas(Census tract 31 and Census Tract 110.22). Among them, Census tract 31(walkability score 70.02) is the most walkable area in the city of Huntsville, which is medium intensity developed area. Census tract 31 mostly covers the downtown area, where the poverty percentage is 28%. Mentionable roads in census tract 31 are Clinton Ave W, church st NW, holmes ave NW, Monroe st NW, and Washington st NW, which are highly walkable regarding both built-in environment and road conditions.

The following Figure 10 shows the mixed land use of census tract 31. The majority of areas are commercial (General Business C-3), but CT 31 has other categories of lands such

as high-density residential, industrial, and a significant portion have low-density residential. It also has a special Medical District zone. Mix land-uses and medium intensity development make CT 31 more walkable than other areas. But another census tract, 110.22, is a medium-intensity developed area, but it has a low walkability score of 20.78. This area has mainly the commercial, industrial park and highway business C-4 zone. Thus, CT 110.22 is a medium intensify developed area, it has a low walkability score.

Census Tract 31

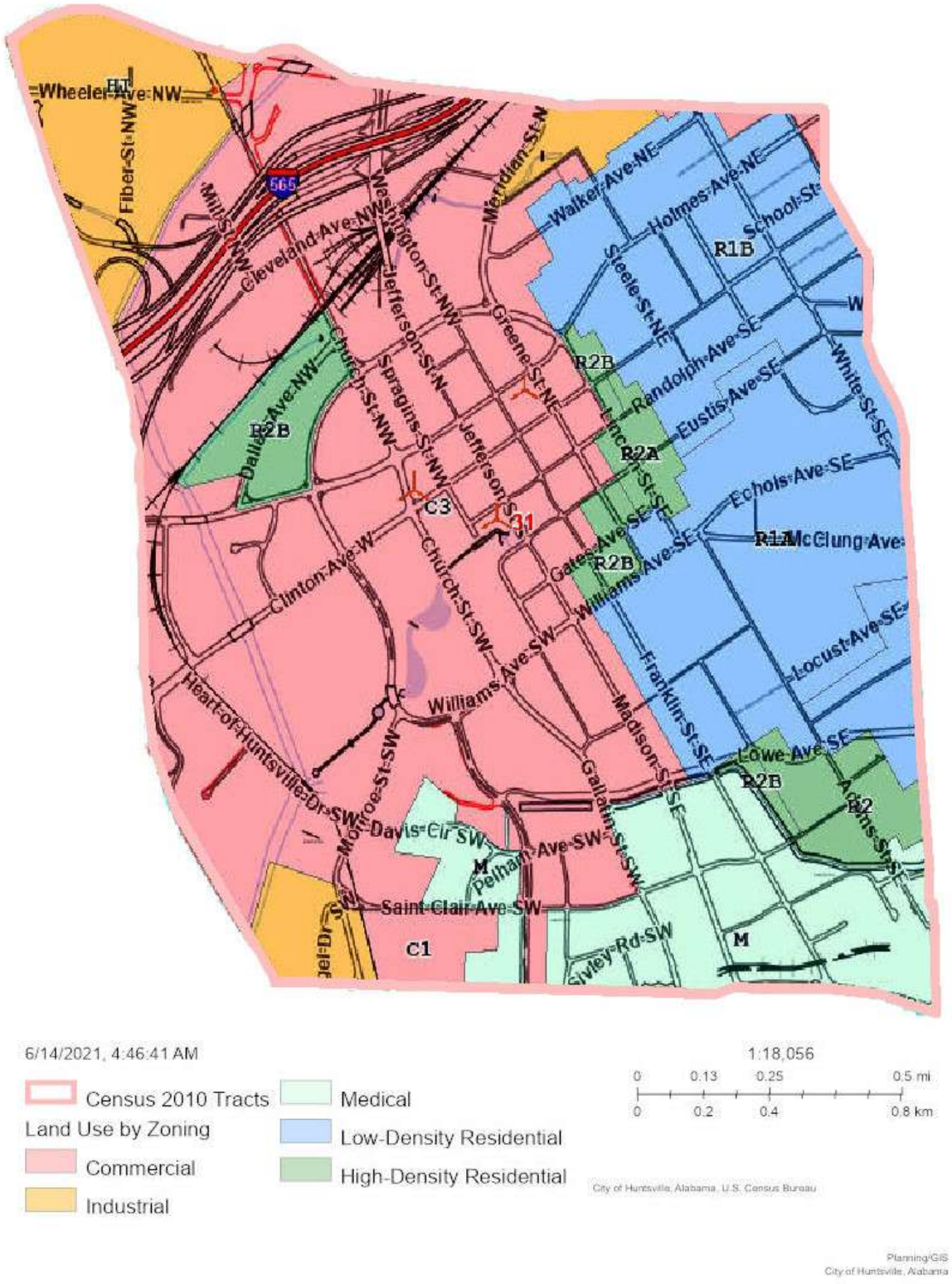


Figure 10: Land Use by Zoning Interactive Map of Census Tract 31

Census Tract 12

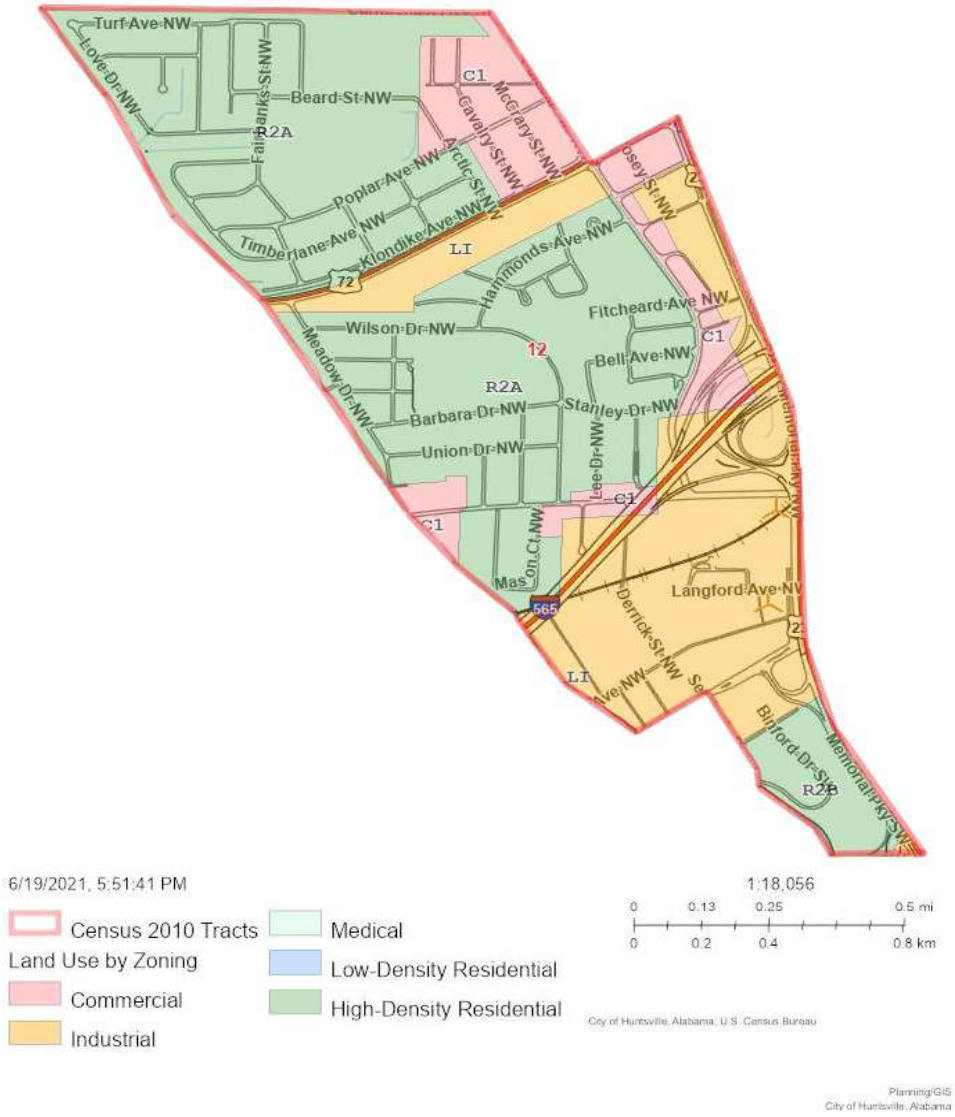


Figure 11:Land Use by Zoning Interactive Map of Census Tract 12

CT 12 is located on the west side borderline of CT 31. The highest poverty percentage and lowest median household income of Huntsville is census tract 12, where the walkability score is around 47, which is high walkable according to the WSAA method. Figure 11 shows that majority of the CT 12 covers low-intensity developed areas that are high-density residential zone. Besides, CT 12 covers industrial(light industry and a tiny portion highway business) and some commercial areas (neighborhood business C-1) too.

These lands are important from the perspective of planning and development because these lands have the most opportunities and open space to plan for the fast-growing development. The following table shows walkability scores, population density, and socioeconomic factors of five census tracts covered by open space-developed land.

Table 11: Walkability scores, population density, and socioeconomic factors of census tracts that are covered by open space-developed land

Census Tract	Walkability Score	Population density (pop/square miles)	Median Household Income	Poverty Percentage
19.03	39.27	1360.94	108221	1.7
27.01	36.10	1764.60	66416	3.4
19.01	22	1408.91	109643	0.6
106.12	13.61	745.89	56071	2.7
106.23	11.46	1166.30	63203	1.2

Table 11 shows five census tracts that have open space developed land. Among them, three census tracts that cover open space-developed lands are 19.03, 27.01, and 19.01 are medium walkable, and the other two census tracts(106.12 and 106.23) have a low walkability score. Population density and poverty percentage is almost similar in all of these census tracts, except 106.12 has lower populaion density than other census tracts in this land category.

Census Tract 19.03



Figure 13: Land Use by Zoning Interactive Map of Census Tract 19.03

Census Tract 27.01



Figure 13: Land Use by Zoning Interactive Map of Census Tract 27.01

Figures 12 and 13 show that the maximum areas of CT 19.03 and CT 27.01 cover low-density residential areas, and a small portion covers commercial areas (Neighborhood Business C-1) and high density residential. The walkability score is medium but median household income is higher than expected. Because both high and low SES people live in these census tracts.

Census Tract 19.01

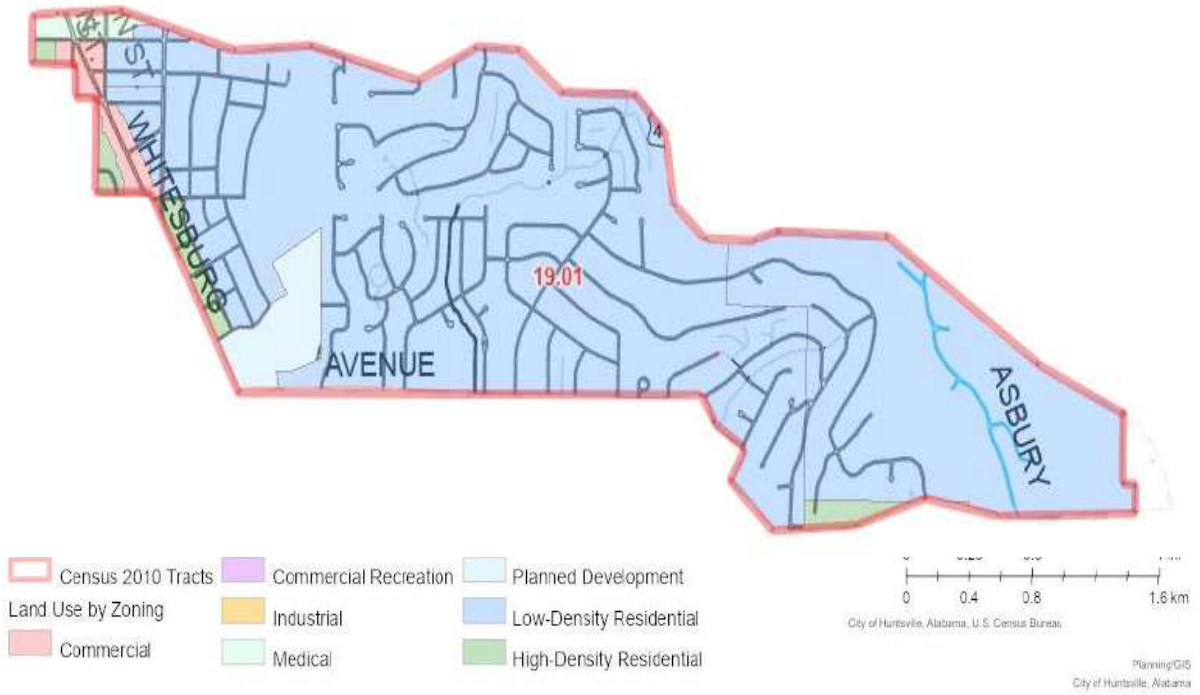
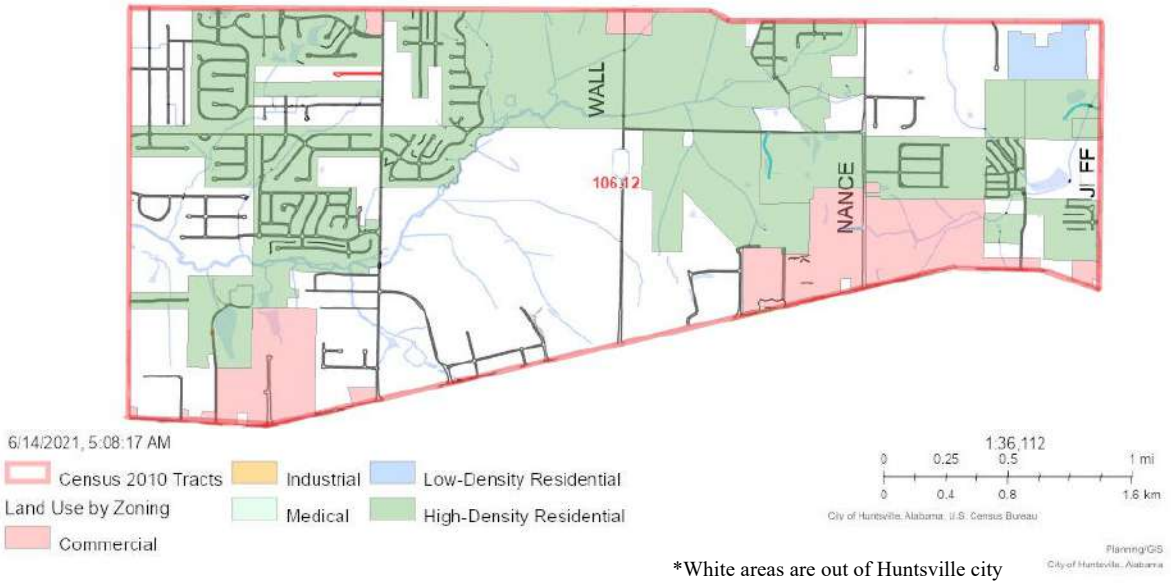


Figure 14: Land Use by Zoning Interactive Map of Census Tract 19.01

Figure 14 shows that almost all census tract 19.01 cover low-density residential areas (R-1A Zone). This census tract consists of communities consisting of single-family dwelling buildings. Besides, a tiny portion covers the planned development-housing and commercial area (neighborhood business C-1 district). Notable that 19.01 has the highest median household income, with a low poverty percentage(only 0.6%).

Census Tract 106.12



*White areas are out of Huntsville city

Figure 15: Land Use by Zoning Interactive Map of Census Tract 106.12

CT 106.12 has the majority of open space-developed lands, but it has a low walkability score(13.61). The reason is that the developed lands are in a separate land zone, such as high-density residential zone and commercial zone(highway business C-4 zone) The above Figure 15 shows the high-density residential and commercial zone of CT 106.12. Census tract 106.12 has a lower population density than other census tracts in the open space-developed land category.

Table 12: Walkability scores, population density, and socioeconomic factors of census tracts covered by deciduous forest.

Census Tract	Walkability Score	Population density (pop/square miles)	Median Household Income	Poverty Percentage
29.12	23.92	1381.24	89739	2.3
29.22	22.74	1709.23	87075	2.1
19.02	20.97	269.87	109576	3.7
18.01	18.75	852.07	83309	1.6
27.22	18.50	1377.36	77617	2.3
2.01	13.58	255.34	28099	35.9
108	10.40	404.90	64062	4.9
109.01	9.83	381.63	87549	1.9

4.03	8.97	346.70	50566	9.7
110.13	8	2610.05	76329	3.4
113	3.40	81.51	40154	7.8

From Table 12, it is noticeable that Census Tract 2.01 has the highest poverty percentage and lowest median household income among the census tract lands covered by deciduous forest. Although such poverty percentage and low median household income, it has a low walkability score.

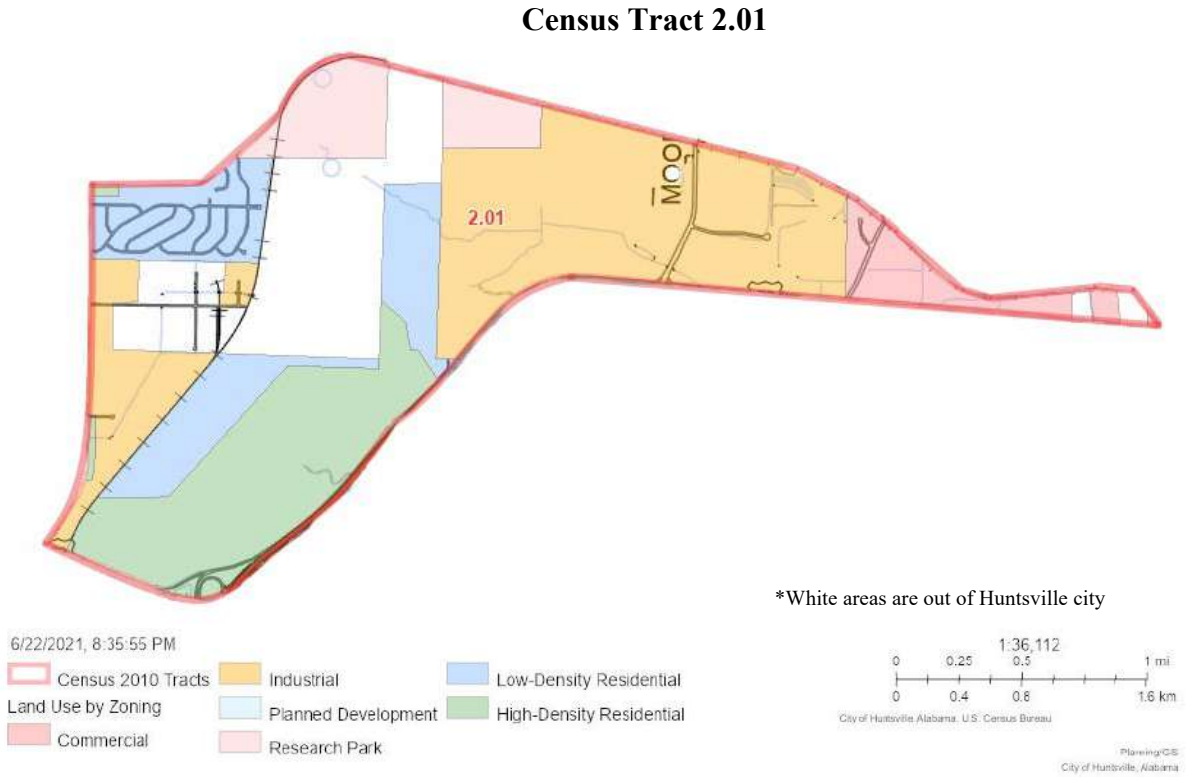
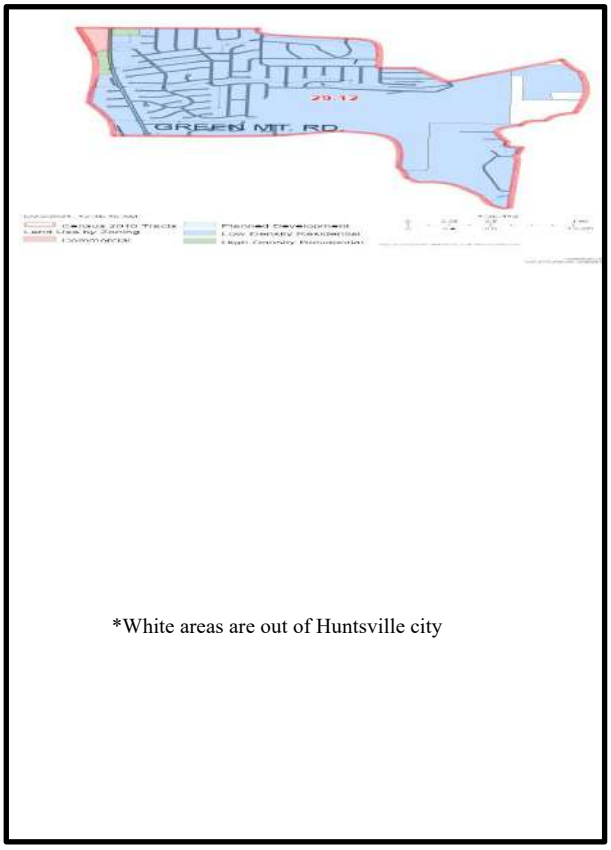


Figure 16: Land Use by Zoning Interactive Map of Census Tract 2.01

Figure 16 shows that the majority part of Census tract 2.01 covers planned industrial. It also covers research parks, low-density residential(R-1B Zone), high-density residential (R-2B zone), and light industrial areas. Thus, it can be said that besides residential zone, a large portion covers industrial zone. Many low-income people reside near these industries. For these reasons, poverty percentage and median household income are low. Although there are

residential, industrial, and research parks in CT 2.01, there are almost no amenities. Hence, the walkability score is low.



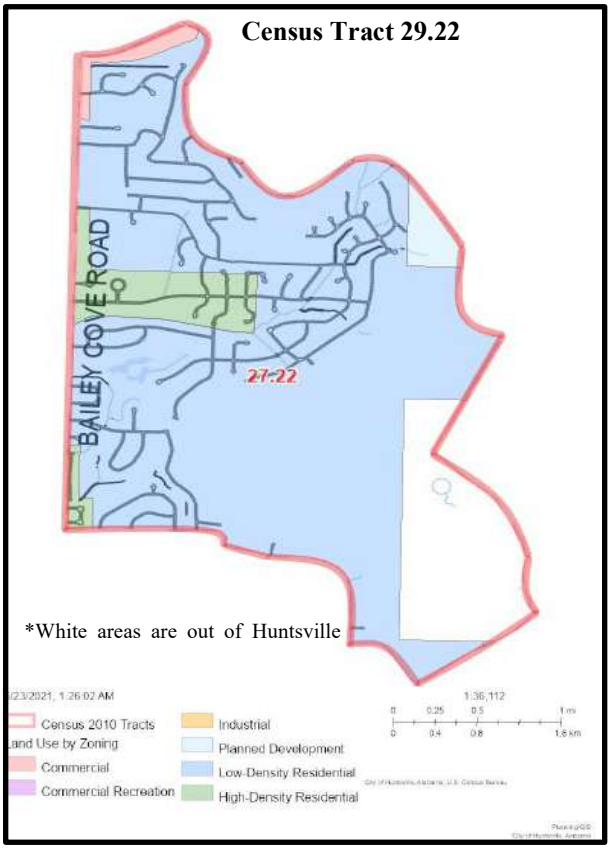


Figure 18: Land Use by Zoning Interactive Map of Census Tract 29.22

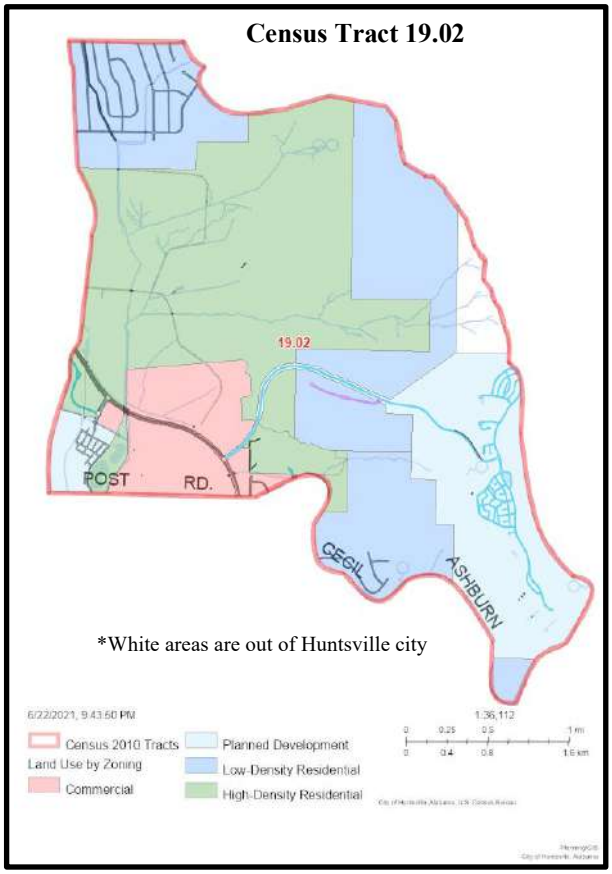


Figure 19: Land Use by Zoning Interactive Map of Census Tract 19.02

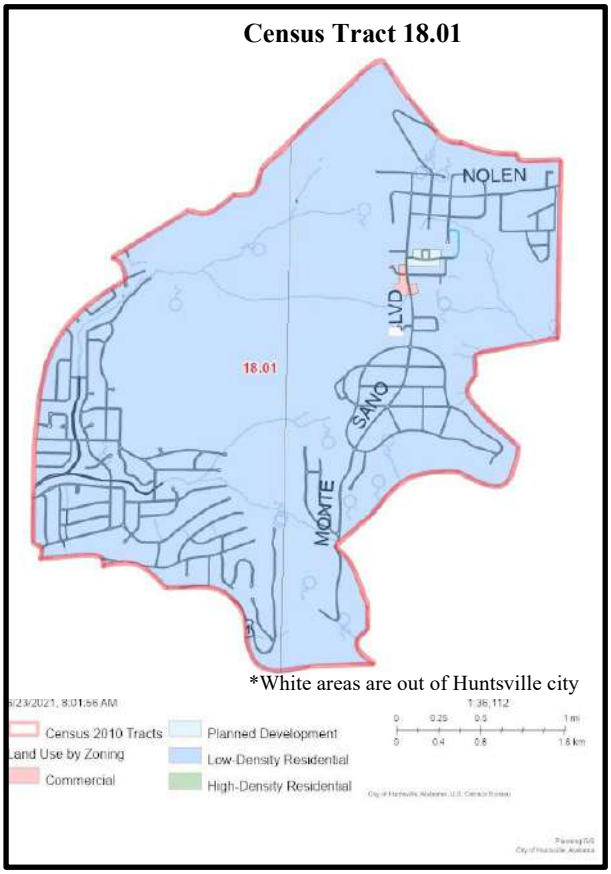


Figure 20: Land Use by Zoning Interactive Map of Census Tract 18.01

From Figure 17, Figure 18, and Figure 20 it can be said that almost all the areas of the CT 29.12, 29.22 and 18.01 that are covered by decidous forest are low-density residential (R1A Zone). A little portion of 27.22 covers high density residential(R2A zone). Besides, a tiny portion of all of these three census tracts cover commercial(neighborhood business C-1 zone). The population density is higher in these three census tracts(1381, 1709, and 852 pop/square miles) than other census tracts that covered deciduous forest because of high density residential zone. The poverty percentage is low and median household income is high in these census tracts as expected.

Figure 19 shows that maximum areas of CT 19.02 covers high density residential (R2A zone). Other lands are commercial (highway business C-4 and neighborhood business C-1 zone), and planned development housing. Noticable than, deciduous lans cover low-density residential, sometimes high density residential, neighborhood business and highway business zone. In CT 19.02, population density is low (269.87 pop/square miles) and median household income is the highest among this land category. Poverty percentage is as low as other census tracts in this category. As maximum lands are only residential and neighborhood commercial zone, all these lands lack mixed use and low intensify developed area, thus generally have less walkability score than low and medium intensity developed area.

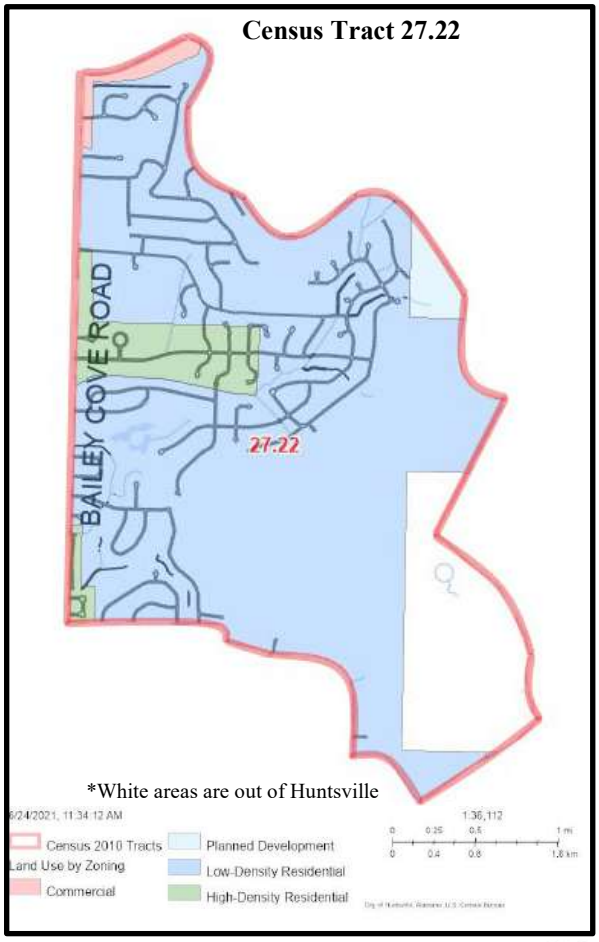


Figure 21: Land Use by Zoning Interactive Map of Census Tract 27.22

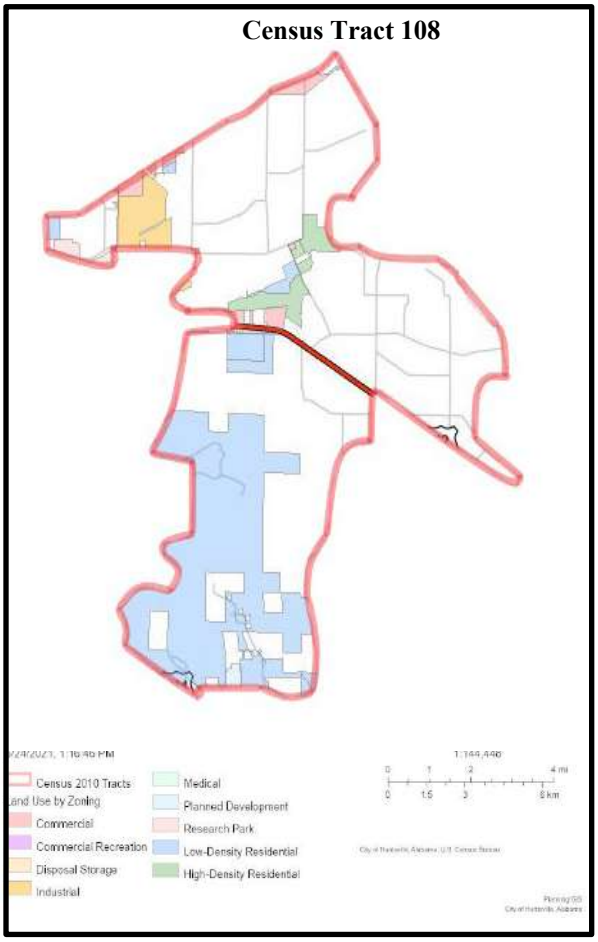


Figure 22: Land Use by Zoning Interactive Map of Census Tract 108

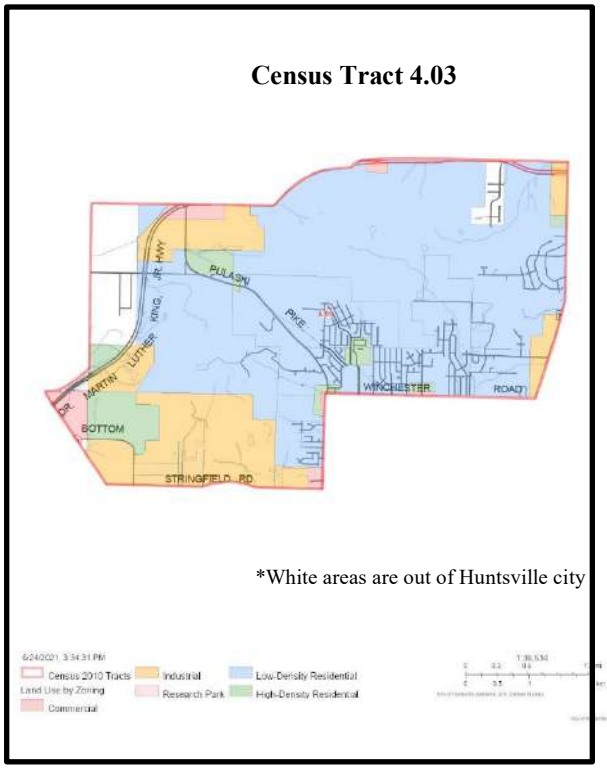


Figure 23: Land Use by Zoning Interactive Map of Census Tract 4.03

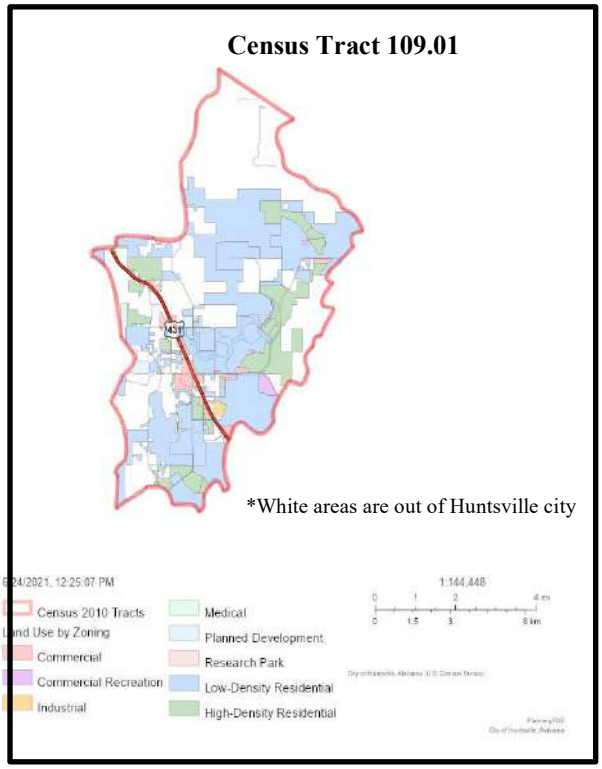


Figure 24: Land Use by Zoning Interactive Map of Census Tract 109.01

Like other census tracts that covered deciduous forestlands, maximum census tract areas 27.22, 108, 4.03, and 109.01 are low-density residential zones. Other areas are high-density residential zone, industrial (planned industry, commercial industrial park), and commercial (highway business C-4). This land category consists of low walkability scores and low population densities with low poverty percentages. The median household income is almost similar to the other census tracts in this land category.

The majority of the other two census tracts mostly cover hay/pasture. The following table shows walkability scores, population density, and socioeconomic factors of census tracts covered by hay/pasture.

Table 13: Walkability scores, population density, and socioeconomic factors of census tracts that are covered by hay/pasture

Census Tract	Walkability Score	Population density (pop/square miles)	Median Household Income	Poverty Percentage
110.11	8.91	2120.77	95144	4.2
111	7.07	30.28	42973	5.9

Surprisingly, the population density of the two census tracts that covered hay/pasture is completely different from each other. Whereas population density in CT 110.11 is 2120.77, the population density in CT 111 is only 30.28. Because a large portion of CT 111 covers Redstone Arsenal and commercial recreation. In the Redstone arsenal area, the population density is very low. Also, notable that median household income is almost double in CT 110.11 compare to CT 111. But both census tract has a low walkability score despite their population density and median household income differences.

Limitation of the Study

In this section, some major issues and limitations of this study were discussed. Initially, the WSAA method has some built-in limitations. It measures walkability based on destination density metrics. Destination density metrics do not consider street furniture and road conditions that affect walkability. Although the purpose of the study aligns with the destination density metrics, the walkability score does not reflect the actual walkability condition. It only reflects the built-in walkability environment.

Furthermore, instead of census blocks, census tracts were used. If census blocks were used, more accurate and precise results might be found. But for the detailed analysis, census tracts were used as the spatial unit for this study. Because interactive maps of Huntsville city are detailed demonstrated by census tracts. Because of low density and low intensity developed area, the results of the analysis of walkability factors by census blocks slightly differentiate from

.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Chapter five has two parts. The first part recommends a potential solution to walkability problems in Huntsville, and in the second part, the thesis concludes by describing the applicable theory that emphasizes initiating a long-term pedestrian master plan.

Recommendations: Creating a walkable Huntsville needs a long-term plan. Although renovating the already established auto-oriented road pattern in Huntsville is difficult, developing small-scale pedestrian-friendly corridors is possible. Table 6 shows that the majority of the 35 census tract lands out of 64 census tracts cover low-intensity developed areas, which is more than 50%. Thus, inserting some density and mixed uses into Huntsville low intensity and low-density lands is possible. But a long-term comprehensive plan is needed to develop step-by-step strategic action. The study result suggests that land-use concerning socio-demographic factors should be prioritized in Huntsville city more than any other factors to initiate a long-term small-scale pedestrian master plan. Six strategic actions are recommended before initiating a long-term pedestrian master plan.

Strategy one: Walking behavior should be analyzed. It helps to understand if the walkability score or destination density increased, walking behavior will be increased or not.

Strategy two: This thesis assesses built-in walkability conditions in every census tract in Huntsville. But a small-scale, detailed, comprehensive assessment is necessary, focusing on similar characteristics corridors based on the interactive map of the city of Huntsville. This comprehensive assessment and evaluation help understand every corridor's land use condition and socioeconomic status. The correlation of socioeconomic status, population density, and land use cover with walkability has already been established in this study. Therefore, analyzing the land use condition and socioeconomic status, categories of missing amenities

should be identified. For example, analyzing the factors, it has been identified that the corridor lacks amenities like primary schools and grocery stores, which is necessary for both low and high socioeconomic status. To validate and verify the analysis, a physical land use survey should be conducted.

Strategy three: After reviewing the land use cover map and interactive map, the identified index should be weighted. The questions that arise here are is it possible to build the amenity there based on land use? And if possible, will the majority of people use that amenity based on SES? For example, it is not possible to build a school in a heavily industrialized area. Again, an expensive restaurant is not suitable for the low SES neighborhood. Moreover, bus facilities and transit stops should be improved and increased in the low SES areas. Mentionable that topography also should be highly considered during the weighing of the identified index.

Strategy Four: A strategic land use development code should be developed. For example, cropland use cover areas lack development intensity and population density. These areas can be commercialized by developing agricultural manufacturing companies that save transportation costs and other relevant costs. As a result, population density and mix-use development intensity will both increase.

Strategy five: Finally, a detailed, comprehensive master plan should be developed. Future potential urbanization should strictly follow this master plan.

Strategy six: After implementing the above five strategies, professionals, practitioners, and policymakers should develop policies and plans for improving the pedestrian environment. Afterward, a complete pedestrian master plan is needed to set the standards and regulations, complete street design, and improving street furniture. Finally, this pedestrian master plan should be developed according to the four city quadrants because the characteristics of these four city quadrants are significantly different based on land use.

The main portion of Northwest Huntsville are mainly low intensify developed areas. The north side border areas are cultivated croplands and deciduous forestlands. The main portion of NorthWest Huntsville is the most walkable place in Huntsville(Figure 4). The development is central-based; thus, almost some parts of the city have no amenities at all. The downtown Huntsville commercial development needs to be expanded. The City of Huntsville should have a policy to expand it to more open areas. The big companies should be established outside of these low-intensity developed areas. Thus, more mix-used land is possible. SouthEast Huntsville land covers Deciduous forest (Figure 7). The maximum area of this region is low walkable. Other land covers open space developed area, and low intensity developed area. A maximum of this regions are forest and hilly area. Massive development can possible in a planned way.

People like hiking. Professionals and authorities should focus on hiking walkability development and plan to develop a less auto-dependent tourist attraction.NorthEast Huntsville is smaller than other quadrants. The area and recommendations are almost the same as NorthWest Huntsville. Almost all areas of SouthEast Huntsville covers by cultivated crops. This quadrant also has a high SES. Moreover, maximum lands are low-density residential zone and almost no amenities. The main factor for creating walkability is increase amenities and other basic facilities with a small-scale area plan.

Conclusion: Creating walkable cities in the USA is not easy. For a long time, more than half of thr US metropolises are automobile-oriented. Thus, it is difficult to break the already established road pattern. But through imagination and persistence, it is possible to increase the walkable environment by inserting some density and mixed uses into low-density cities[5]. Although enhancing the walkability condition in this automobile-dominated age is challenging, it is possible to encourage design and planning professionals for a long-term sustainable plan.

From the WSAA map, it can be said that the professionals should focus on scattered development in Huntsville. Central development is one of the inherent for creating a walkable environment in Huntsville city. For these reasons, in the WSAA map, almost all far distance areas from the central downtown area are not walkable or low walkable. Although southwest areas are hilly regions, there should be a separate pedestrian development plan because hiking is very popular among many people. However, the authorities should focus on developing potential growing tech-industrialized areas and scatter the development from the center to all areas in Huntsville with a comprehensive master plan on that area that supports mixed land use development

On the other hand, it has been found that socioeconomic status does not impact walkability in Huntsville. Hence, mixed-use development and proper strategic planning policy should be included. Proper planning also brings horizontal and vertical social equity and spatial accessibility, beneficial for the marginalized peoples of Huntsville.

Considering health, environmental, and other significant issues walkability concept is becoming popular in the United States of America like other countries. Mainly people realize the global warming factor in the big picture, which creates fire hazards, environmental pollution, health damage, less productivity, and so on. Designing a walkable city can be a substantial step to prevent these disasters. Accessibility to different points of interest where

people regularly visit is one of the most important indicators for measuring walkability. Furthermore, this leads to identifying walkability problems in various census tracts in Huntsville city. Mixed land use can increase the necessity of building more walkable roads and developing pedestrian facilities, leading to a pedestrian master plan in Huntsville City. In few words, to create and establish a pedestrian-friendly and walkable city, the Government and individuals have to take short-term initial steps and a long-time comprehensive master plan. Relatively lower-income areas are more walkable in Huntsville but not according to the standard walking environment. Also, Huntsville lacks balanced and mixed-use development, which is also an important economic development factor. The study concludes that before focusing on the pedestrian-friendly walkway, it is essential to prioritize scattered and mix-land use development because these developments lead to initiating a long-term pedestrian master plan in Huntsville. It is the most technologically advanced city in Alabama State. This city structure is suitable for higher-income people, but it lacks social and economic equity in all sectors. Finally, the Government has to focus on developments that support social and economic equity, which will also be helpful for overall development in Huntsville City.

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APPENDICES

Appendix A

MEAN WALK SCORE® AND WSAA GENERATED WALKABILITY SCORE OF 64 CENSUS TRACTS IN THE CITY OF HUNTSVILLE

Census Tract	WSAA Score	MEAN WALK SCORE®
31	70.01960754	64.20863309
20	63.05454636	54.13529412
26	53.96116638	40.26886792
7.02	53.19230652	33.73333333
6.01	50.4871788	28.96808511
22	50.40476227	49.53703704
13.01	48.68421173	39.70930233
30	48.43877411	44.93137255
12	47.768116	47.64766839
7.01	47.4603157	33.41860465
17	43.21154022	28.20915033
15	41.71052551	51.5047619
23	41.70491791	45.17938931
25.01	39.9679985	46.75912409
19.03	39.27272797	19.48571429
21	38.82500076	62.35548173
28.01	37.98787689	35.73891626
10	37.55356979	59.05063291
2.02	37.2159996	22.3880597
13.02	36.5263176	37.13483146
27.01	36.09889984	26.61142857
106.22	34.46540833	26.98881432
6.02	33.5263176	23.51785714
5.03	33.4736824	22.88679245
29.11	30.46721268	16.5
3.01	30.13829803	20.82608696
5.02	28.8125	26.25974026
24	26.52727318	22.87356322
3.02	26.33333397	20.90322581
14.02	26.29916382	20.77850163
5.01	25.32307625	28.848
29.12	23.92380905	13.12865497
29.21	22.77611923	13.26644737
29.22	22.73913002	7.569444444
27.21	22.60194206	21.09502262

19.01	22	21.04313725
19.02	20.96621704	12.04487179
110.22	20.77777863	15.87096774
28.02	19.63982964	14.39782016
25.02	19.2620697	17.39759036
18.01	18.75378799	5.96875
27.22	18.50427437	17.30674847
9.02	18.29090881	16.29927007
14.01	17.01922989	10.60416667
106.12	13.61111069	7.479338843
2.01	13.58461571	7.728813559
106.21	12.73684216	3.350649351
9.01	12.54245281	13.05208333
106.23	11.46173477	1.53164557
108	10.39627647	5.537037037
109.01	9.831298828	4.895922747
4.03	8.97132206	10.64333333
110.11	8.909090996	16.25
110.13	8	12
111	7.071428776	17.47619048
208.02	4.5	3.807407407
112	4.23294878	3.754662841
113	3.98775506	1.978540773
107.02	3.578313351	6.982758621
109.02	3.574468136	3.611111111
107.01	3.537815094	3.611111111
105.02	2.641025543	0.230769231
212	0.101796404	1.497777778
211	0	0

Appendix B

HUNTSVILLE CITY CENSUS TRACT DEMOGRAPHIC DATA AND WALKABILITY SCORE

Census Tract	Walkability Score	Pop Per Sq Mi	Median HH Income	Poverty Percentage(%)
31	70.01960754	1781.38237	22319	28
20	63.05454636	2401.792794	45378	8.4
26	53.96116638	2531.181201	52906	16
7.02	53.19230652	2169.179189	27828	21.3
6.01	50.4871788	2690.662874	47033	24.9
22	50.40476227	3452.416057	26649	38.1
13.01	48.68421173	4234.386923	25908	42.7
30	48.43877411	2008.778196	23963	45.5
12	47.768116	3181.955396	13918	64.7
7.01	47.4603157	2931.733469	31706	29.8
17	43.21154022	2284.675148	69832	2
15	41.71052551	2573.967286	33639	31.3
23	41.70491791	5085.764582	32030	45
25.01	39.9679985	1682.204648	22351	55.1
19.03	39.27272797	1360.937051	108221	1.7
21	38.82500076	2645.97345	18294	56.9
28.01	37.98787689	1314.125162	45987	20.6
10	37.55356979	3209.852341	34042	19.8
2.02	37.2159996	2097.563674	36661	42
13.02	36.5263176	1981.418477	39592	26.8
27.01	36.09889984	1764.604496	66416	3.4

106.22	34.46540833	1171.960754	40968	27.8
6.02	33.5263176	3143.524379	37925	29.4
5.03	33.4736824	2883.637376	50279	10.4
29.11	30.46721268	2361.439417	76840	1.9
3.01	30.13829803	2731.497917	34965	30.3
5.02	28.8125	3027.879744	42256	20.1
24	26.52727318	4569.127723	28908	41
3.02	26.33333397	2441.824033	32215	26.3
14.02	26.29916382	610.8627693	43593	24.1
5.01	25.32307625	1668.521628	51639	17
29.12	23.92380905	1381.23864	89739	2.3
29.21	22.77611923	1735.949126	54528	16.3
29.22	22.73913002	1709.234546	87075	2.1
27.21	22.60194206	2417.304909	75155	9
19.01	22	1408.908673	109643	0.6
19.02	20.96621704	269.8748825	109576	3.7
110.22	20.77777863	1875.197919	55410	12.8
28.02	19.63982964	1231.412359	66408	6.9
25.02	19.2620697	1315.656795	35113	32.8
18.01	18.75378799	852.0709314	83309	1.6
27.22	18.50427437	1377.36368	77617	2.3
9.02	18.29090881	2375.031387	42510	11.6
14.01	17.01922989	917.109451	64311	6.5
106.12	13.61111069	745.8908918	56071	2.7
2.01	13.58461571	255.3355742	28099	35.9

106.21	12.73684216	786.4812619	101474	2.6
9.01	12.54245281	1126.271846	56821	11.7
106.23	11.46173477	1166.30067	63203	1.2
108	10.39627647	404.9019301	64062	4.9
109.01	9.831298828	381.6292457	87549	1.9
4.03	8.97132206	346.7046898	50566	9.7
110.11	8.909090996	2120.768651	95144	4.2
110.13	8	2610.052155	76329	3.4
111	7.071428776	30.28464606	42973	5.9
208.02	4.5	373.1142242	59976	3.6
112	4.23294878	265.7591643	62643	6.9
113	3.98775506	81.51430533	40154	7.8
107.02	3.578313351	524.38106	54765	14.6
109.02	3.574468136	95.40681329	37578	17.6
107.01	3.537815094	229.8011284	57370	7.1
105.02	2.641025543	189.9267988	54506	18.3
212	0.101796404	92.60032802	48420	9.8
211	0	72.05665474	38633	10