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ANALYSIS OF TRANSIT ACCESSIBILITY FOR PEOPLE WITH DISABILITIES

by

Rostam Khalid Mohammed Ameen Qatra

A thesis submitted to the Graduate College
in partial fulfillment of the requirements
for the degree Master of Science in Engineering (Civil)
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ANALYSIS OF TRANSIT ACCESSIBILITY FOR PEOPLE WITH DISABILITIES

Rostam Khalid Mohammed Ameen Qatra, M.S.E.

Western Michigan University, 2016

The inconvenience of public transit systems and unavailability of bus stops in the United States has resulted in a heavy reliance on the private automobile. One of the main issues in transit services is accessibility, particularly for people with disabilities. This research is intended to compare estimated job accessibility measures by transit in Kalamazoo county for workers with reduced physical mobility and without. Using OpenTripPlanner (OTP) software, General Transit Feed Specification (GTFS), Open Street Map (OSM) and Longitudinal Employer-Housing Dynamics (LODES) data were analyzed to estimate job accessibility for people with mobility constraints. By using the shortest tree path method, OpenTripPlanner (OTP) calculates a series of origin-destination matrices with multi-modal travel times and distances. The developed Python scripts estimate AM peak accessibility measures at five-minute intervals for four time thresholds (30, 60, 90 and 120 minutes). This research addresses the two main research questions. First, have we provided sufficient access to jobs through public transit for people with disabilities for their mobility independence? Second, how do we select bus stops to add wheelchair accessibility in the context of better job accessibility for people with disabilities?

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LIST OF SYMBOLS

ADA	American with Dissabilities Act
ADAAG	American Dissability Act Accessibility Guidelines
CBSAs	Core-Based Statistical Areas
DLZ	Top consulting in the surveying industry
GTFS	General Transit Feed Specifications
IVR	Interactive Voice Response
K-Metro	Kalamazoo Metro Transit Agencey
LEHD	Longitudinal Employer-Household Dynamics
LODES	LEHD Origin-Destination Employment Statistics
OTP	Open Trip Planner
OSM	Open Street Map
PROWAG	Public Rights-of-Way Accessibility Guidelines
PAR	Pedistrian Access Route
rac	Residence Area Characteristics or Workers by Place of Residents
TIGER	Topologically Integrated Geographic Encoding and Referencing

List of Symbols - continued

wac	Workplace Area Characteristics or Jobs by place of Works
BRT	Bus Rapid Transit.
ITS	Intelligent Transport System
APC	Automatic Passenger Counters
NTD	National Transit Database

1 Introduction

The first chapter is arranged into four distinct topic areas. Within each subject range, extensive preliminary information on accessibility and public transit is provided. These discrete areas are as follows: (1) Statement of the Problem, (2) Significance of the Problem, (3) Objective and Scope, (4) and Accessibility, which is separated as Definition, Factors that Affect Accessibility, and Measurement of Accessibility.

1.1 Statement of the Problem

Inconvenient public transit systems in the United States of America has impeded personal mobility and resulted in the use of private automobiles, instead of the use of public transit. This is more serious for people with physical mobility constraints. Disabled workers face difficulties in commuting by transit, which have significant influences on their independence of life. Effective and convenient transit systems with accessible bus stops can lead to plentiful environmental, economic, social benefits achievement and associated infrastructure.

Public transit can be defined as a network of vehicle systems, such as trains and buses, which are operated on scheduled times and fixed routes, and with a capacity to carry numerous transit riders with different origins, destinations, and purposes.

When compared to driving, public transit is much more straightforward, trouble-free (especially in winter), and inexpensive for customers. An example is a recent marketing campaign by Metra indicating that "Metra makes your life 10X easier!" Transit should be encouraged to improve mobility for both younger and older adults who have either reduced mobility or who are unwilling to drive a private car or do not have access to a private car.

As stated by Mobility International USA (2016), inaccessibility of bus stops for individuals with impaired physical mobility is a common problem everywhere, a fact that makes their lives less secure. For example, about seventy percent (70%) of bus stops in Kalamazoo County in Michigan are inaccessible by persons with mobility constraints, according to the DLZ survey. With this high percentage of inaccessible bus stops, many individuals who are disabled suffer from a loss of independence. Yet, due to budget constraints, it is very difficult to make all bus stops wheelchair-accessible.

In 2014, DLZ MICHIGAN, INC. conducted a survey that gathered data on bus stops and shelters to determine if they were compliant with the requirements of the 2010 Americans with Disabilities Act Standards for Accessible Design (ADASAD). The survey revealed that many of the bus stops and shelters were not completely compliant with the ADASAD and recommended a total of $506,000 for bus stop improvements, as well as an additional $21,000 dollars to make the shelters

compliant. Therefore, the decision for selecting bus stops for improvement should be made in a cost-effectiveness manner, based on potential improvement of accessibility for workers with disabilities. This study analyzes operations and services for people with and without disabilities by extending the application of General Transit Feed System (GTFS) data.

1.2 Significance of the Problem

Encouraging people to switch to public transit is a significant way in keeping transportation systems sustainable. This is true due to countless advantages of public transit, such as less congestion, and a cleaner environment by reducing air, land and, water pollutants, including greenhouse gas emissions through decreased energy consumption. In addition, public transit could improve public health with other active modes of transportation, including walking and cycling. Increasing accessibility to the bus stops will increase accessibility of jobs through transit because according to Tomer et al. (2011), jobs are a significant part of the daily movement of people.

Therefore, all public transit facilities should be universal in design and accessible, especially for people using wheelchairs, to give them more independence to reach their job destinations. Furthermore, elderly age, which is the future of everyone, has the highest percentage of wheelchair users. In 1990, due to the Americans with Disabilities Act (ADA) individuals with disabilities should not be discriminated against in service areas, facilities designs, activities or any other

programs on the basis of disability. As we know, about 70% of the bus stops are not accessible in Kalamazoo county, a fact that may have a significant negative impact on the independence of those people. Therefore, this problem is significant and action should be taken expediently to address this issue.

In addition, giving priority to the bus stops that can serve the highest percentage of workers with disabilities is significant as well. Therefore, bus stops that should be improved must also be economically based to have a stronger influence on rider accessibility and reach out to most workers with disability within budget limitations. Finally, local jurisdictions such as Kalamazoo, Portage, Oshtemo, Comstock, Texas and the office of the ADA Coordinator in Kalamazoo county Administrator, which are responsible for improving these bus stops, can take advantage of this research due to the economically efficient outcomes.

1.3 Objective and Research Scope

The significant goal of this research was to evaluate how individuals with impaired physical mobility access their jobs and reach these destinations. Then, the study prioritized the bus stops that need to be improved to provide better access and more independence for people with constraint mobility. Kalamazoo county was selected and analyzed as a study area. According to the DKZ survey (2014) conducted to evaluate difficulties experienced by individuals who use wheelchairs, 70% of bus stops in Kalamazoo county are inaccessible by wheelchairs.

To perform this analysis, the study area, Kalamazoo county, was divided into block boundaries defined by the U.S. Census Bureau, and then block centroids were identified in ArcGIS. These are fundamental units of accessibility in this research. For analyzing the study area, the Open Trip Planner (OTP), an open-source analysis, was used to calculate travel time and to measure accessibility in this research. Timetable and transit network in GTFS format and pedestrian and street network data from Open Street Map were combined by OTP through the unified graph building process.

GTFS data from K-Metro transit has transit routes, stops, and schedule time data inside, which represent a significant part in this research and which measured travel time. Next, GTFS data were modified for people with reduced physical mobility, based on the GTFS data standard format and the survey data for bus stops. This step was carried out by DLZ for compliance with the requirements of the 2010 Americans with Disabilities Act.

In this research, the labor and employment distributions were drawn by the U.S. Census Bureau. Workers by place of residents (residence area characteristics) were used as origin demand, and jobs by place of work (workplace area characteristics) as destination attraction (Longitudinal Employer-Household Dynamics program LEHD, LODES, 2013). Consequently, OTP was run to measure accessibility and assess system performance across neighborhoods. The number of jobs and workers reachable by transit systems for people with and without constraints

in mobility are compared. The results were calculated for both cases, and then the results for analysis were used to compare both case scenarios and to establish an analytical framework for exploring Title VI compliance.

1.4 Accessibility

1.4.1 Definition

Accessibility is the potential for interaction and exchange. According to Litman (2011), accessibility is the ease of people's ability to reach destinations, such as services, goods, and activities, which all together are defined as opportunities. Among them, job opportunity is the most significant. Transport planners mostly concentrate on mobility, but land use planners normally concentrate on geographic accessibility, such as distances between activities. The vital goal in transportation planning, land use planning, and building design is accessibility. The word, accessibility, has been around about a half century (Handy, 2002) and covers different meanings and implications in planning areas. The general meaning concerns the physical access to activities, services, goods, and destinations, which define the concept of transportation for individuals.

In roadway engineering, usually access is a connection between adjacent places. Least connections to nearby places refer to limited access to those roads. At the same time, local roads make direct access available. Driveways on highways and intersections managements are controlled by access management, such as giving green time access to a specific road in an intersection. In the urban economics and

geographic field, accessibility states to the relative straightforwardness of reaching a particular and specific destination. Also, pedestrian planning and facility design are made more convenient to accommodate people with disabilities. Such a design should be a universal concept, which means an accessible design. For example, designing pedestrian road access or a pathway to accommodate people with reduced mobility requiring the use of wheelchairs might be defined as accessibility. In social planning**,** accessibility relates to people's capability to use services and opportunities that are part of everyday life for most people, from engaging in social activities to engaging in professional work opportunities (Litman, 2011). This research concerns job accessibility by transit and walking, as well as bus stop accessibility for people who use wheelchairs, in measuring job accessibility.

1.4.2 Factors That Affect Accessibility

In general, numerous features that affect accessibility but Litman (2011) described specific factors affecting accessibility as summarized below:

1- Supply and Demand Transportation Activities: Usually supply related to transit request for different activates which is strongly counted for in motorized travel demand but in non-motorized less counted for. It covers the amount of mobility and access and businesses people would choose.

2- Mobility Movement: Normally, people look for travel speed and distances on their trip. Therefore, vehicle speeds and mileages traveled are significant for them in accessibility.

3- Transportation Options and Performance Measures: Performance measure and the value of (speed, convenience, comfort, safety, etc.) are significant to choose the quality transportation mode, such as walking, cycling, public transit, and others. They have a huge impact on accessibility. In auto mode, speed or arrival time, convenience, and safety are usually take into account. On the other hand, walking and cycling mode accessibility factors are neglected.

4- User Information and Guidelines: This factor has a significant impact on accessibility options. If the information is reliable, it will help transit riders on transit mode choices and accessibility.

5- Well-Integration, Accessible Terminals and Parking Spots: Having a well-connected transport, providing enough parking spot around stations have a significant influence on accessibility, especially public transit because the level of connectivity among transport system links and modes rise accessibility.

6- Low-cost Tickets: Daily income of the passengers is related to transit mode choice to travel to their jobs. If the cost of using a mode increase, affordability

for using that mode will decrease, such as public transit usually designed for low income people. Therefore, transit fares are important to be considered.

7- Mobility Replacements: It is not that much significant in transportation planning. Sometimes other options are used for transfer services and goods instead of physical travel such as telephones and delivery services.

8- Land Use Factors: Population or worker density, are considered in land use planning while fewer in transport planning. However, it has a significant on daily movement. Therefore, land use density and mix are significant.

9- Connectivity of Transportation Road Network System: Roadway connectivity is highly considered in transportation planning because it has a huge impact on accessibility. Therefore, the density of transport network connections, the place of the bottleneck, and the directness of travel between destinations are significant. In addition, the quality of multimodal connections, such as ease of walking and cycling to public transport stations, especially for people with reduced mobility and using a wheelchair significant too.

10- Transportation System Management: Accessibility level highly related to well organization and traffic system management in the area, such as delay management and other concern.

11- Prioritization: This factor is somewhat significant, especially in congested cities and metropolitan areas and give priority to buses by having a special

lane for buses like Bus Rapid Transit system (BRT). These methods more common and efficient in travel activity in crowded cites such as New York.

12- Inaccessibility: Unreachability and isolation should be considered to not affect a special group in a community. For example, inaccessibility of bus stops in Kalamazoo county has the influence on disabled people. Therefore, cost estimation should be considered for improving inaccessibility.

1.4.3 Accessibility Measures

A methodology or method of calculating or measuring accessibility is termed an accessibility measure, which is the process of measuring accessibility. Accessibility measures are organized into four bases such as opportunity, utility, gravity, and space-time. In this study, opportunity-based measure was selected to deal with the job opportunity numbers that are reached within a 2-hour travel time limit and 30, 60, 90, and 120-minutes time thresholds by particular mode (e.g., public transit and walking). The cumulative opportunity measure was utilized in this report. It is one of the two major opportunity-based measures, which sums the quantity of job opportunities that can be reached from each origin within a specified travel time (Yin et al, 2015).

2 Background and Literature Review

2.1 Introduction

This chapter discusses the background and literature review on accessibility through transit systems for various activities, General Transit Feed Specification (GTFS), performance measures, and Title VI. In addition, standard requirements for bus stops in compliance with ADA requirements are discussed. For each subject, a list of papers has been reviewed.

2.2 Background

Public transit can be defined as a mode of transportation provided locally that consists of regularly scheduled trips and the capacity to carry many people along set routes with different origins, destinations, and purposes. Two common entities such as public and private of public transit have been announced as a separate part. Increased investment in public transport may result in fewer cars on the road and would lead to environmental sustainability, due to decreased toxicity. Transit is the second most commonly used commute mode after driving. In the United States, about 5 percent of commuting trips is carried out by public transit (Owen and Levinson, 2014).

Breathing in a cleaner and a healthier place is the common concern of environmentalists. Dramatically growing numbers of cars on the roads all over the world contribute to the idea that transport engineers and planners must consider the

ways in which future generations of individuals will use public transit. Therefore, making transit accessible to everyone has a significant impact on the number of cars on the roads.

The advantages in the use of public transit include lessening of environmental pollution in the air and water, fewer automobile crashes, less traffic congestion and less energy consumption. In times past, the government spent great sums of money on building infrastructures and road improvements; however, in the next century, it must try to invest in public transit and facilities to attract passengers and to switch them from the use of their autos to the use of public transit. Therefore, it is essential to improve the pedestrian environment and routes to encourage people to walk and cycle, and to make transit and bus-stops accessible for everyone.

One proposal concerns the payment of a congestion fee that automobile owners should pay to cover expenses for producing harm to human and environmental health (Suzuki et al., 2013). Then, in addition to a fuel tax, public transport could be improved by this money, and possibly influence more car drivers to switch to transit.

Buses, trains, and trams are the most common public transport vehicles that are used by the public and which require a fare and/or require access to a ticket. Generally, public transit allows people to travel together along set routes. Therefore, public transport is important for communities. Usually, elderly or disabled people

receive a discount, thereby facilitating the collection of data about this particular group. One of the valuable ideas of decreasing number of cars on the roads are giving free travel for students via transit, such as college and schools. In most of the places, this idea has been performed, such as in Kalamazoo, where Western Michigan University students are allowed free use of the K-Metro transit.

2.3 Accessibility Through Transit

2.3.1 Accessibility for People Without Disabilities

Accessibility refers to the people's capability to reach valued destinations, such as services, goods, and activities. Accessibility can be measured by its destinations, such as jobs, grocery stores, hospitals and clinics, fire stations, schools (public or private), parks, libraries, etc. Numerous scientific researchers have been working on accessibility for different types of activities and from different perspectives. Owen and Levinson (2014) evaluated job accessibility via transit in 46 out of 50 of the largest metropolitan population areas in the United States. They ranked 46 metropolitan areas based on the weighted average of accessibilities.

In their ranking determinations, the highest weight was given to the nearest jobs that require the lowest travel time. That is, jobs accessible in 10 minutes were more heavily weighted than those accessible in 60 minutes. The measurements were calculated with various time limits, such as 10, 20, 30, 40, 50, and 60-minute thresholds. Using OTP, the researchers calculated travel time from GTFS and other

general data based on block level geographic boundaries. According to their findings, among all the metropolitan areas in the United States, 10 of them with the highest accessibility to jobs via transit such as, New York, San Francisco, Los Angeles, Washington, Chicago, Boston, Philadelphia, Seattle, Denver, and San Jose (Owen and Levinson, 2014).

Yin et al. (2015) combined mobility and land use with accessibility measures to offer a more sufficient and comprehensive output of the transportation-land use correlation. In their paper, they demonstrated a web-based system that pictures multimodal accessibility to various land uses in the Chicago metropolitan area. Accessibility measures were broadly categorized into four classes: opportunity, gravity, utility-based, and space-time. GTFS data from all three public transit agencies in the Chicago region were used: CTA (Chicago Transit Authority), the bus and subway service provider of the city of Chicago; PACE the suburban bus service provider of the Chicago area; and Metra, the commuter rail agency in the Chicago metropolitan area. They used job-count data and eight other land use count data.

Widener et al. (2015) analyzed people's spatiotemporal restrictions of supermarket access. The data analysis in Cincinnati, Ohio showed that a substantial number of citizens developed better access to supermarkets when shopping on the way back from their work locations than departing from their home location. This study utilized an interaction potential measure, which was derived by applying an

estimation of the distinctive time space limitations on public transit traveling for populations departing from work locations, as well as an equivalent measure where trips to the supermarket began from the home location. Travelling flow data delivered statistics on residents' patterns of movement, from home to work locations, and vice versa (Widener et al, 2015).

Todd Litman (2011) correlated accessibility with transport planning. He stated that services, goods, and activities that can be seized by individuals is called accessibility, which is the significant factor of most transport activity. He described accessibility factors, such as affordability of various transport modes and quality, interconnectivity of transit systems, mobility substitutes, land use patterns, and mobility. In his paper, Litman examined different viewpoints to estimate accessibility and cover a particular group, location, or activity mode. His point was that some of these critical factors and perspectives could be overlooked and devalued due to predictable planning, and it was important to examine and analyze widespread accessibility when considering potential solutions to transport problems. The results showed that developed accessibility opportunities and cost reduction of accessibility and improvement can help attain many social, economic, and environmental advantages s (Litman, 2011).

2.3.2 Accessibility for People with Disabilities

Facilities should be designed universally to accommodate all users, especially people who depend on mobility aids such as mothers with a baby in a stroller, and elderly people in wheelchairs or using walkers. Pedestrian road access should be improved for narrow roads, in short blocks, and pedestrian shortcuts, which have a mixed-land use. The significant issues have been facing people with physically reduced mobility in Kalamazoo county is the inaccessibility of bus stops connected with pedestrian road access, and suitable platform compliance with ADA requirements. There are many researchers who have worked on accessibility for people with physically reduced mobility in different kinds of sectors, such as accessibility of buildings, technology, jobs, and others. Nearly 18,479 workers with disabilities, both males, and females, are in Kalamazoo county due to 2013 American Fact Finder.

Hara et al. (2015) argued for the improvement of public transit accessibility for blind riders by crowdsourcing bus stop landmark locations with Google Street View. The researchers introduced and evaluated a new climbable method for collecting bus stop locations and landmark descriptions by joining online "crowdsourcing and Google Street View (GSV)" together (p. 1). In their paper, they emphasized specifically on the role of landmarks in helping impaired vision and blind people to recognize bus stop locations, by operating special tool they built called "Bus Stop (Crowdsourcing Streetview Inspections)" (p. 1). It collected workers

together and directed them. Also, it marked bus stop signs and surrounding landmarks in GSV. They testified on three studies. In the first study, they interviewed some people with visual impairments, part of them had not a functional vision to notify the design of their crowdsourcing tool. These interviews extended and emphasized the importance of nonvisual landmarks in helping blind/low-vision travelers to find and verify a bus stop location. In the second study, practical inspections were performed between audit data with Google Street View and an online study for comparison. In the third study of their paper, a unique structural tool was utilized to examine the feasibility of crowdsourcing bus stops using audits. This unique structural tool called "Amazon Mechanical Turk (MTurk)". The data described in their paper are composites of the following: first, components of a broad coalition of stakeholders, such as transportation providers, human services agencies, transit patrons, and other citizens, and state and local government. Second, strategies for advancing common agendas for transportation, such as identifying regional travel needs and developing regional transportation strategies, as well as administration and management strategies, evaluation strategies, and organization methods. The study stated that the best way to reach the valued destination successfully is related to provide transit information services, such as routes, timetable or headways, and fares. The major goal of Hara et al. is improving coordination between public transit providers in different agencies, as well as tools, strategies, and organizational structures across

American communities. For this purpose, different case studies were clarified in different regions in their paper. (Hara et al., 2015).

Church and Marston (2003) argued measuring accessibility for people on a landscape of surfaces, barriers, and travel modes. They proposed a new viewpoint for measuring accessibility, with an emphasis on people with differing abilities especially for people with a physical disability. The goal was to remove barriers in buildings and urban design to improve accessibility for limited-mobility people, because accessibility is a goal in transportation planning, land use planning, and building design. They projected an accessibility measurement structure with different equations that includes measures of absolute access, gross access, and closest assignment access, single and multiple activity access, probabilistic choice access, and relative access. Their agenda efforts codified a method that helped to overcome weaknesses and challenges in utilizing the absolute access measurement alone, which is presently used in compliance with ADA. Campus design at the University of California at Santa Barbara (UCSB) helped to underscore the significance of measuring relative accessibility, while the researchers discussed the problem with respect to wheelchair riders. They said that others like "pushing lads in strollers, paramedics pushing a gurney, campus audio-visual personnel pushing TV carts, and courier personnel with a package cart" (Church and Marston, 2003) (p. 93) came across the same type of challenges and physical barriers in moving across campus. Providing equal access to all is the goal of the ADA. This performance was beneficial

to improve access to different facilities, such as public area facilities, which include "libraries, parks, and courthouses and private sector facilities such as theaters, motels, and stores" (Church and Marston, 2003) (p. 95). However, the convenience of accessible toilets plays a significant role in making the circumstances of a facility valuable. They clarified that discrepancies in access will continue to exist, since money is spent on restoration, makeover, and eliminating barriers across the urban landscape, consideration should be focused on making cost-effective choices, and the highest-level development in overall accessibility. Their goal is measuring accessibility for people with disabilities, but for different activities, and removing barriers in building design and transportation planning, which is related to the connection of loading zones and buildings compared to job accessibility via public transit (Church and Marston, 2003).

Marston et al. (1997) intended to explore blind or low-vision peoples' travel behavior, specifically travel by bus. Data was used to differentiate the sample that relied on the number of cars per household which was obtained from United States Census Bureau. Their methodology explored perceptions of and attitudes toward available transit and different transit characteristics. The paper emphasized features that may become obstacles and challenges for those people who are blind and vision-impaired. This population uses dissimilar assistive devices that have potential usefulness, and which have been evaluated for traveler assessment. One of the useful features of the devices is information that gives navigational assistance.

The most relevant part of Marston et al.'s (1997) paper talked about disabled blind people and the problems they face regarding using public transit. They defined who are the disabled people, activity and travel behavior, and explained survey, and procedures and why people use public transit. The most difficult situations faced by disabled people especially blind people while using public transit is recognizing which vehicle to enter, estimating where a person is when the vehicle starts in motion, dealing with layovers when the route changes, dealing with crowded vehicles, finding transfer points when changing vehicles, finding transfer points when having to cross the street, entering or exiting transit vehicles, and finding an empty seat (Marston et al., 1997).

2.4 General Transit Feed Specification (GTFS) Background

The early history of releasing General Transit Feed System goes back to 2005 that Portland's TriMet published their GTFS data structure. Beyond that, more transit agencies released their transit timetable in the GTFS format structure. It opened a way for transportation modelers to think more deeply and take advantages of this beneficial data. They assessed the value of this data and used it for various purposes along with Google Maps. Also, it has been developed with technology, they combined with varieties of software applications in transportation, multimodal accessibility, timetable creation, and mobile apps. Nowadays, there are a lot of people have utilized GTFS data for various purposes, below some of them.

Eros et al. (2014) applied the general transit feed specification (GTFS) in Mexico City. Authors indicated that (GTFS) has become the standard factor for releasing public transit route and schedule data. The case study clarified that even for a megacity with multi-transit availability, it could make a fully functional GTFS feed. The project discovered untapped potential significance to mark the importance and worth of the ecosystem data, mainly for regulatory tools and planning. There were two constraints, stop location and scheduling, for GTFS data, but an adaption to GTFS developed in Mexico City addressed this limitation. The methodology of this paper applied GTFS data and classified it into static or dynamic, which shows the real time bus location (GTFS-RT). Also, they used various mobile applications to make easy for riders from their point of locations to be able to show Metro station locations and trip-planning directions. Mexico City began generating its first GTFS feed by enrolling the relevant agencies in the process. A minimum of two stops along a trip indicated the other intermediate points for boarding and alignments are forecasted by interpolation method through GTFS data. The data sources and data used in this paper consist of GTFS data collection experiences across five cities and their characteristics such as city population, metropolitan population, and primary transit modes, such as microbus, metro, bus, regulatory scale, transit trips per day, Internet access, mobile phone ownership, Smartphone ownership, and Transit Data Outputs.

Eros et al. focused on low- and middle-income place and recent deployment of GTFS feeds in Mexico City. This case focused on services in the Federal District

SETRAVI which oversees six relevant services. The advantage that GTFS data apps provide are trip planning and predictions of bus arrival times and locations to reduce rider waiting time and to increase future ridership. This is done by improving access to high-quality transit services and increasing the satisfaction levels of current riders. Joining various sources of data with the GTFS feed may possibly help urban planning agencies incorporate land use and transport in small cities.

In Mexico, a GTFS feed was based on defining headway between two buses and regular intervals for fixed stops. It is also dependent on some knowledge base in the area for GTFS data, instead of a schedule. For example, arrival time due to passengers' experiences and travel time from location to location due to transit drivers' experiences GTFS was modified by taking the form of a more flexible version of the GTFS data with optional fields for stop locations, schedule data, and frequencies (Eros et al., 2014).

Puchalsky et al. (2012) developed a regional forecasting model based on Google Transit Feed. The main objectives of developing this model was developing a process that included data translation, combined with further data sources, and adjustment of the components model that are not involved in GTFS. For example, transfers, transit access, final path-building and choice and demonstration of fare represent several of these components. Also, the authors clarified the obstacles and profits of GTFS utilization in a regional predicting model and gave insight in the

current state of model validation. The data used in their report involved data sources such as Web 2.0 and represent the progressive accomplishments of various groups of users on a voluntary basis, as well as Google's GTFS data and Open Street Map. The methodology in this research explains three subjects. First, what is GTFS data; second, why Delaware Valley Regional Planning Commission made the decision to use GTFS to build new transit network and third, integration of GTFS with the other sources, such as DVRPC's travel forecasting software, which has three major steps. First, translation of GTFS into the model design format; second, joining of the GTFS stops and routes with the highway network consequent map (OSM); and third, public transport data improvements, such as transfer numbers, stop arrangement, fare coding, auto and walk access, adjustment of building path, and choice.

One of the important factors that has a significant impact on accessibility by transit is location. For example, the city center of Philadelphia offers a higher level of accessibility by transit when compared to suburban locations. Nineteen staff-months of time were required to produce the new transit network and of these 19 months, 70% were from full-time staff, while 30% were from interns. In conclusions, DVRPC effectively accomplished GTFS data in the Greater Philadelphia's regional travel-predicting model to state transit service (Puchalsky et al., 2012).

Wong (2013) used the General Transit Feed Specification (GTFS) in transit performance measurement. The main objectives validated "GTFS feeds are an

efficient data source for calculating key transit service metrics and to evaluate the validity of published GTFS feeds as a data source by batch processing them and comparing the results to metrics in the National Transit Database NTD" (Wong, 2013) (p. 2). The result compared to well notify future researchers and transit analyzers on the use and limitations of the GTFS data. "The author created a tool for his methodology called the GTFS reader to demonstrate GTFS feeds' analytic potential, which basically imports GTFS feeds into a database using open-source products" (p. xii). His final findings show that well-organized GTFS feeds are an exact depiction of transit networks and the metrics for transit agencies measured effectively and efficiently by the technique of combination offered in his report. The aggregation of a daily-based approach was most correct than the aggregation of a weekly-based approach in terms of accuracy. In larger agencies, the dependability of GTFS feed data is more certain than that of smaller agencies due to inconsistencies discovered in smaller companies during their GTFS-generated metrics that were compared to those in the National Transit Database (NTD). In conclusion, one way to provide information about an agency's service is to develop and report performance measures that accurately represent different factors of the service. Offering free-access data for resident action in structural of data analysis had opened a clear way for more other options in public agency operations. The result of his research is a validation of GTFS data and the GTFS Reader framework for use in practical performance measurement (Wong, 2013).

2.5 Performance Measures

Development and assessment of performance measures have a key role in evaluating and improving regional transit coordination by using GTFS Data. In this project ArcGIS spatial database together with Python scripting to implement the performance measures. Area type and characteristics have a significant role in developing performance standards and statistical relationships among measurements. There are a lot of books and guidebook for developing performance measurement system among them TCRP in 2002. It helps managers of transit systems in this development. In this guide book non-traditional and traditional measures were used to state customer oriented and public concerns. Adding transit-focused performance measures is beneficial to metropolitan planning organizations if performed to their planning efforts. It is useful to collect and report to the National Transit Database which helps identify how good service is provided to their customers. The reasons behind using performance measures in each transit agencies are: it is obligatory, beneficial to the transit agencies, and others out of transit agencies boundary necessary to have knowledge about what is going on (TCRP, 2002).

"The performance measures in the TCRP guide book are revealed as bellows" (p. 7):

1) Transit Obtainability: Having sufficient capacity and location and time service is provided.

2) Service transport: Cover dependability, passenger provision, customer boarding, and agency aim.
3) Protection and safekeeping: Involved in an accident or become the victim of a crime while using transit.
4) Maintenance and construction: Effectiveness of maintenance program, and impacts of construction projects.
5) Economic: Transit performance assessed from a business viewpoint, including use, effectiveness, efficiency, and administrative measures.
6) Community: Evaluates transit's impact on individuals and on the community in general, such as (community, agency, and vehicle driver).
7) Capacity: Capability and efficiency of transit facilities.
8) Travel time: Taking time to make a trip by transit by itself, in comparison with another mode or with an ideal value.

2.6 Standard Requirements for Bus Stops

The requirement of the bus stops for people with a disability is different from that of normal people. All bus stops in America should be matched with the requirements of the American standards accessibility design, which is called "Americans with Disabilities Act Standards for Accessible Design" (ADASAD), as declared in 2010. Significant parts of consideration for ridership with physically

reduced mobility are connecting to pedestrian access routes and providing boarding platforms, which include sidewalk facilities, curb cuts on their routes and bus stops for fixed-route transit services. The requirements for bus stops with wheelchair accessibility should comply with ADASAD/PROWAG requirements, which include Title II regulations at (28 CFR 25.151) and 2004 ADA accessibility guidelines (ADAAG 810.2). All bus stops should be connected to pedistrian access route and have platforms. Also, all public transit vehicles should be 100% wheelchair accessible to carry wheelchair riders. Table 2-1 below shows the requirements for platforms and bus stops to become wheelchair accessible.

Table 2-1 “Bus stop requirements from (DLZ, 2014) (p. 4)”.

Parameter	Requirement	Pertinent Regulation
Platform Surface	Must be firm, stable, and slip resistant	PROWAG R302.7
Platform Dimensions	Clear length 8 feet minimum perpendicular to the street and 5 feet minimum parallel to the street.	PROWAG R308.1.1.1
Platform Grades/Slops	Shall not exceed 2% in any direction. On existing platforms, the slope of the platform is permitted to be equal to the grade of the street to the extent practicable, perpendicular to the street the grade shall not be steeper than 2%.	PROWAG R308.1.1.2 PROWAG R308.1.2.2
Connection	Boarding platforms shall be connected to a sidewalks or pedestrian pathes.	PROWAG R308.1.3.2
Vertical Alignment	Surface shall be free of level changes that exceed 1/4 in, or ½ in if leveled to avoid presenting a trip hazard	PROWAG R302.7.2
Horizontal Openinigs	Surfaces shall not have openings that exceed ½ in, including cracks joints, or other openings.	PROWAG R302.7.3
Benches	If present, 50% (1 minimum) must has a 30x48 in clear space on one side that meets the same surface requirements as PROWAG R302.7.	PROWAG R212.6 PROWAG R404.3
Obstractions	No object is permitted to reduce the required clear widith dimensions	PROWAG R210
Overhead Clearance	Overhead vertical clearance shall be 80 inch minimum.	PROWAG R402.4
Protruding Objects	Objects shall not protrude more than 4 inches into the pedestrian circulation path between 27-80 in	PROWAG R402.2

Source of data obtained from K-Metro transit

3 Data Collection

3.1 Socio-demographic Information about Kalamazoo County

Kalamazoo county is located south of the state of Michigan in the US, as shown in Figure 3-1. Kalamazoo county began in 1830, although the origin date is unknown. Bronson was the first name of the village of Kalamazoo in 1831 (Clarke, 1954).

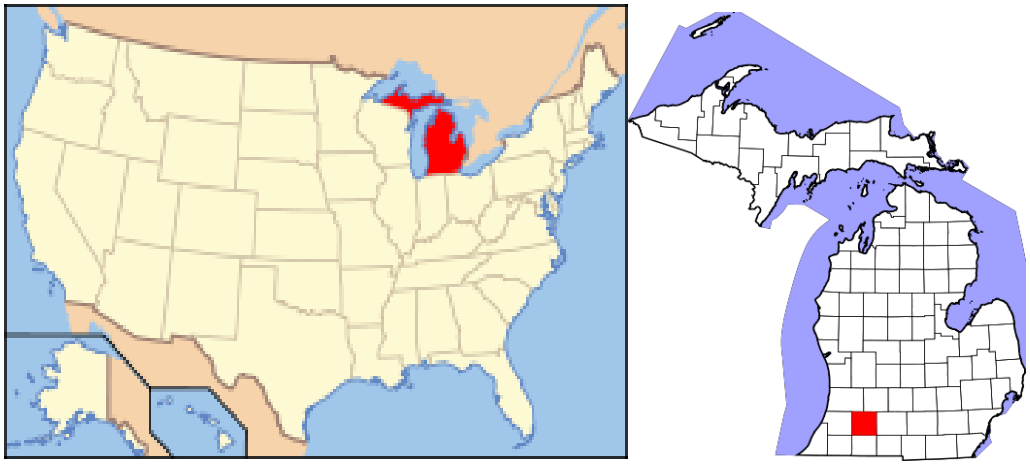


Figure 3-1 Highlights State of Michigan and Kalamazoo County.

As of 2013, American Fact Finder estimated the total population at 256,725. Different ethnic groups are divided as follows: Caucasian was 211,594; Black or African American was 28,773; American Indian and Alaska Native was 1,287; Asian was 6,619; Native Hawaiian and Other Pacific Islander was 165, and Two or More Races was 8,287. The total area is 580 square miles (1,502 km^2) or 562 square miles (1,456 km^2) land and 19 square miles (49 km^2), 3.2% water.

The density of Kalamazoo county population is 456.8/square miles (176.32/km²) in 2013. For the same year, the City of Kalamazoo had a total estimated population of 75,122, and the City of Portage had a total of 47,140. Kalamazoo is the major city of the Kalamazoo-Portage Metropolitan Statistical Area, which has a population of 326,589, as of the 2010 American Fact Finder. Figure 3-2 shows an example of the thematic map of population density per square mile for block group level in the 2013 Census Bureau in Kalamazoo county.

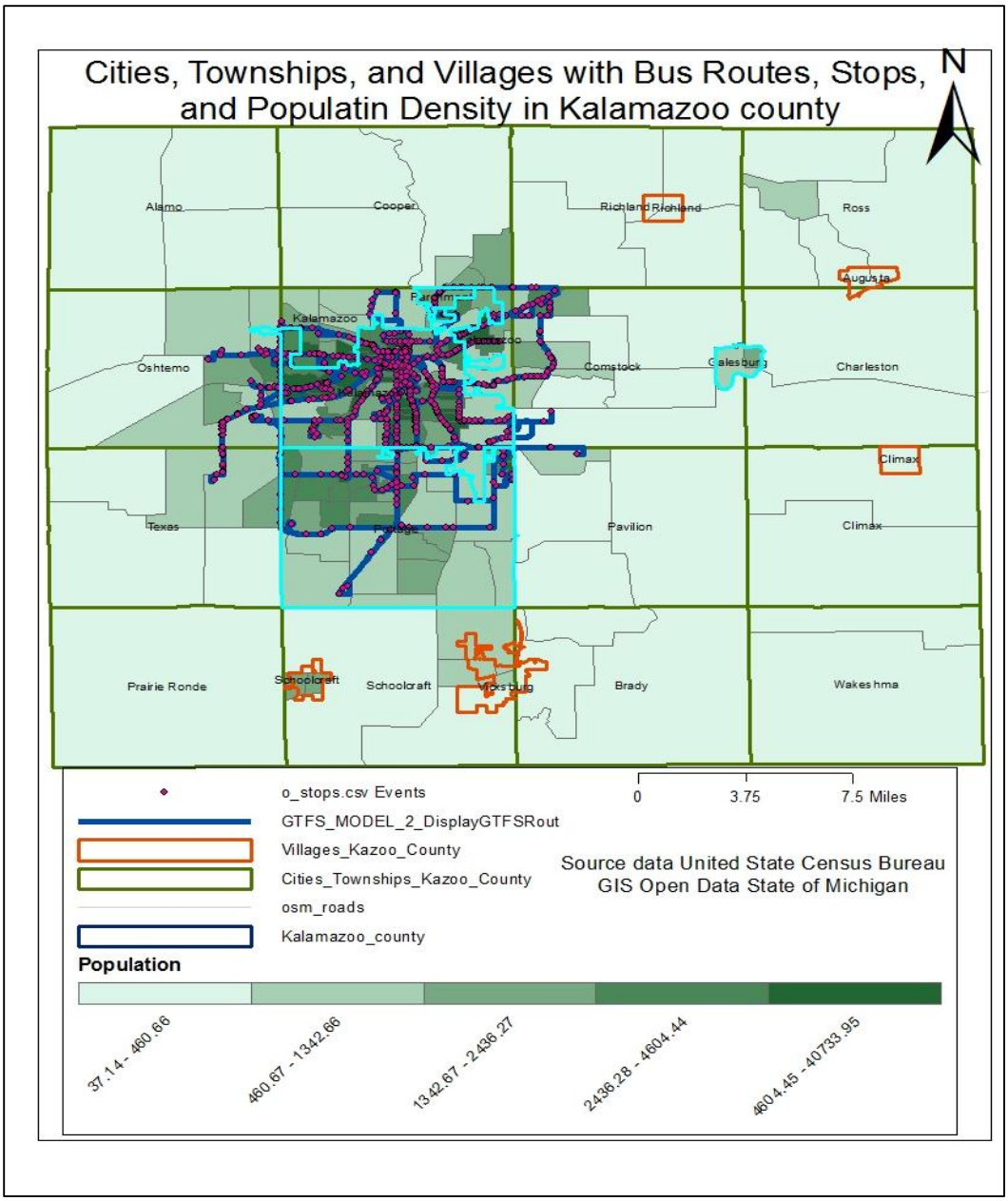


Figure 3-2 Population density per square mile with cities, townships, and villages in Kalamazoo county.

Kalamazoo county has four cities: Galesburg, Kalamazoo, Parchment, and Portage. Of these, Kalamazoo is the largest. There are sixteen townships, which

include the following: Alamo, Brady, Charleston, Climax, Comstock Charter, Cooper Charter, Kalamazoo Charter, Oshtemo Charter, Pavilion, Prairie Ronde, Richland, Ross, Schoolcraft, Texas Charter, and Wakeshma. Also, Kalamazoo county has five Villages: Augusta, Climax, Richland, Schoolcraft, and Vicksburg as shown in Figure 3-2 (U.S. Census Bureau, 2013).

In 2013, Kalamazoo county the total number of jobs by place of work were as follows: 113,706 jobs, and the total number of workers by place of residence was 97,866 workers. The total number of Caucasian workers was 85,028 workers and Black or African American workers were only 9,176 workers. The numbers and density are shown in Figure 3-5. The location of jobs and workers are shown in both figures by block level as a thematic map of Kalamazoo county, which starts by a small block area in the center then becomes bigger block sizes near the edges. Job density for all Kalamazoo county is 202.324 jobs per square mile (or 78 jobs per km^2), as shown in Figure 3-3. Worker density is 174.14 workers per square mile (or 67.2 Workers per km^2), as shown in Figure 3-4. Both White and Black or African American workers' density thematic maps are shown in Figure 3-5. There are 5,785 blocks within Kalamazoo county. The total number of bus stops is 736 stops in GTFS data (DLZ, 2014).

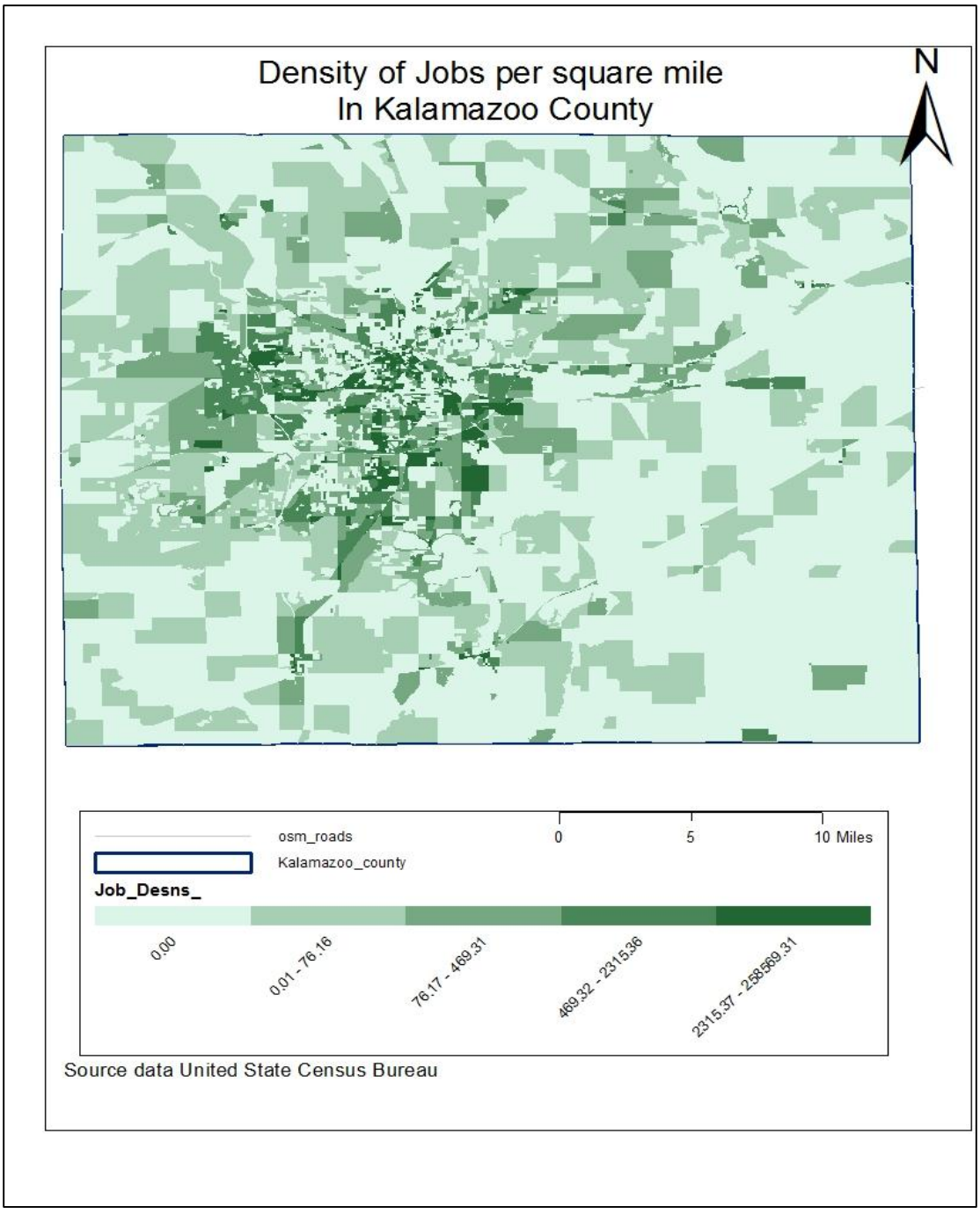


Figure 3-3 Thematic map of jobs density in Kalamazoo county.

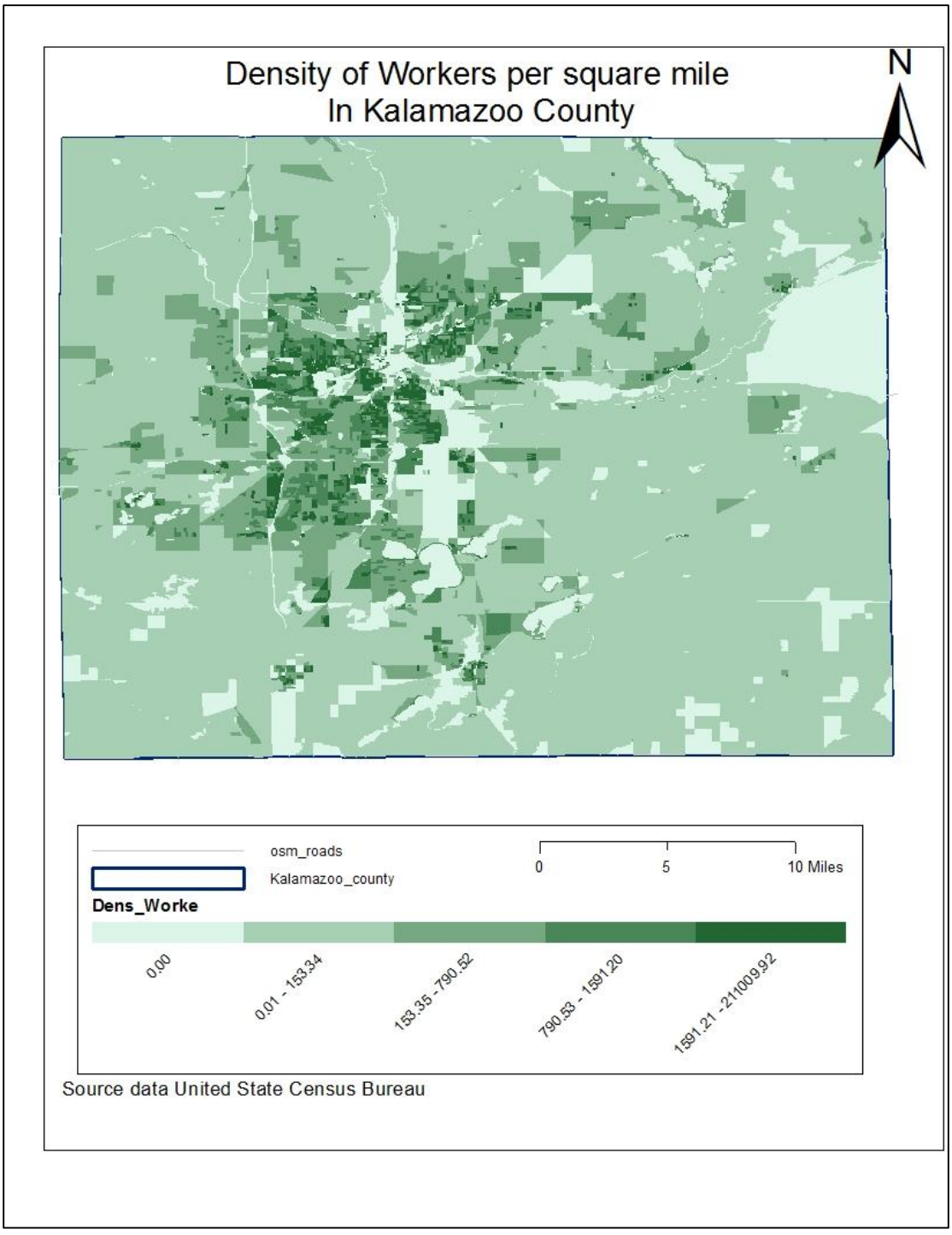


Figure 3-4 Thematic map of worker density in Kalamazoo county.

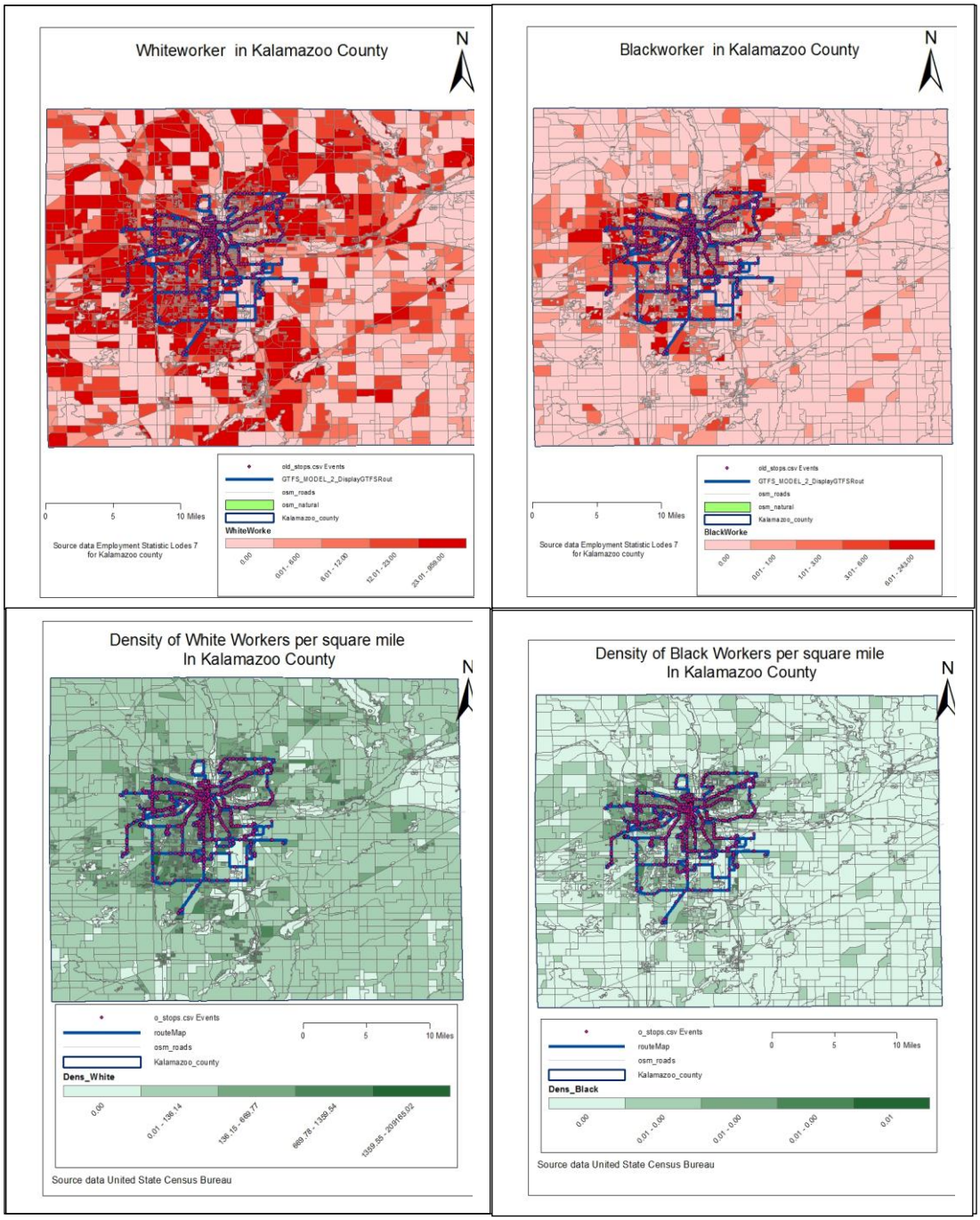


Figure 3-5 Thematic map of Caucasian/Black or African American workers by place of residence in Kalamazoo county.

One of the active public transits in the study area is K-Metro transit, which serves the community in two ways: fixed route buses and the Metro County Connect service (K-Metro, 2016). The Metro County Connect service is required by federal law and serves from curb-to-curb for ADA/Paratransit service. It is available for those who have reduced mobility, because it is difficult for an individual with a physical or cognitive disability to use a regular fixed-route bus service. People with disabilities and seniors have priority, and because the service travels all over Kalamazoo county, there 45 coaches used for this service. Generally, community service vans are accessible for use by agencies that have provided a certified driver to transport their clients who may not be able to use fixed-route bus transportation. This research project recommends a solution for disabled people who are not able to use fixed route transit.

Fixed-route public transit service in Kalamazoo covers three big cities in the Kalamazoo county area: Portage, Kalamazoo and Parchment, as well as the following townships: Cooper, Kalamazoo, Comstock, Texas and Oshtemo. Metro Transit schedule time starts from Monday to Saturday each week from 6 am to 10:15 pm each day. Services were not provided on some holidays. Frequencies of the route could be 15-minutes, 30-minutes, 45-minutes, or 60 minutes. There are a total of 19 regularly fixed routes operating for K-Metro transit, as shown in Table 3-1 with their trip mileages.

Approximately 3.1 million trips were taken in 2013. System network size consisted of 36 buses in the service. All vehicles were totally accessible for individuals with disabilities. Approximately 2500000 miles fixed route service and 3100000 passenger trips annually had been provided by Kalamazoo Metro Transit. It had provided local funding source to the company.

Table 3-1 Total trip miles for each routes with inbound and outbound mileages form K-Metro Transit.

Miles by Trip All Routes				
Number	**Route**	**Outbound**	**Inbound**	**Total**
1-	Westnedge	5.7	5.8	11.5
2-	Portage	7.2	7.1	14.3
3-	W. Michigan	6.1	4.4	10.5
4-	Oakland	5.5	11.8	17.3
5-	East Main	3.1	2.8	5.9
6-	Parchment	7.5	7.7	15.2
7-	Alamo	5.9	6.2	12.1
8-	Egleston	6.5	8.9	15.4
9-	Gull Road	7.2	5.5	12.7
10-	Comstock	8.6	8.2	16.8
11-	Stadium	8.5	8.1	16.6
12-	Bronson	7.5	7.5	15

Table 3-1 - continued

13-	**S.** Burdick	4.7	4.6	9.3
14-	West Main	6.2	6.1	12.3
15-	Paterson	2.1	1.6	3.7
16-	Lovell	5.8	5.8	11.6
17-	West Centre	4.8	13.2	18
18-	East Romence	9.5	9.9	19.4
19-	Solon / Kendall / Lafayette	5	0	5

In October 2012, the Socio-Economic Survey, conducted by the Kalamazoo Area Transportation Study, indicated that 73% of the riders are those passengers who have no other option to travel (captive rider) for the following reasons: no driver's license or no automobile available in their household. The others are choice ridership.

As shown on the K-Metro website (2016), the breakdown of ridership is based on various criteria, such as:

- Sex: Female=54%, Male=43%
- Race: White=38%, Black=35%, Hispanic=4%, Asian=5%
- Trip target: Shopping=5%, Medical=5%, Social/Recreational/Other=15%, Work=25%, School=33%.
- Age: Elderly Over 61 years=5%, 43 to

61 years=24%, 23 to 42 years=36%,16 to 22 years=31%, and 0 to 15 years=2%,

- Income Level Per Family: $0 to 4,999 = 30%, $5,000 to 9,999 = 14%, $10,000 to 14,999 = 15%, $15,000 to 24,999 = 15%, $25,000 to 34,999 = 6%, and more than $35,000 = 12%. (The city of Kalamazoo, 2016).

3.2 Data Collection and Sources of Data

The data that have been analyzed in this project were collected from different reliable sources. The survey data on bus stops about accessibility and inaccessibility wheelchair boarding were carried out by DLZ MICHIGAN, INC and contracted by K-Metro transit agency. Transit schedule or General Transit Feed Specification (GTFS) including timetable data used in this research, obtained from K-Metro and the Transit App website (http://www.transitapp.com).

Standard format and modified GTFS data format related to adding the wheelchair boarding field relies on Google Developer that can be obtained from the following URL: (https://developers.google.com/transit/gtfs/reference#stopstxt). Furthermore, core-based statistical areas (CBSAs) as geographic data, such as blocks, tracts, block groups, and places were obtained from U.S. Census TIGER 2010 datasets.

The most important data for analysis, such as workers by place of residence (residence area characteristics) and jobs by place of work (workplace area characteristics), and relevant for race such as Caucasian and African American or Black, were obtained from U.S. Census Longitudinal Employer-Household Dynamics LEHD Origin-Destination 2013 and Employment Statistics (LODES) Origin-Destination files. These data can be downloaded from the following URL: (http://lehd.ces.census.gov/data/). Latest Open Street Map (OSM) for Michigan, which is an open-access online record was obtained from the geofabrik website (http://download.geofabrik.de/). The analysis was done by OpenTripPlanner (OTP), which is an open source program and ArcGIS program, which is available at the Transportation Research Center for Livable Communities (TRCLC) lab. The disabled workers' data to prioritize bus stops and to improve accessibility were all obtained from American Fact Finder (United State Census Bureau) by block groups boundary.

3.3 Data Preparation

To begin with preparing the data, due to the large size of the area, the study area was divided into block boundary levels, and divided CBSAs into analysis zones for effective parallelization, then found block centroid to make a points.csv file, which has x, y coordinates from block centroid along with GEOID. Python script was written to build a graph from GTFS data and then connected with street and pedestrian networks in the latest Open Street Map (OSM). The graph of the unified

pedestrian-transit network was built for each analysis zone based on latest OSM for road network and GTFS data for the transit set route network and the transit schedule to calculate walking distance and travel time from each origin to multiple destination were connected based on OTP graph function program. Both residence area characteristics workers by place of residents and workplace area characteristics jobs by place of work were joined with block centroid to make an origin destination file. GTFS data were modified with regard to accessibility limitations for people with disability cases. Modifying GTFS data in cases related to wheelchair accessibility were started by adding a column in a stop.txt file called wheelchair_boarding for stops based on the stops survey carried out by DLZ MICHIGAN, INC in October 2014, and adding another column in the trips.txt file called wheelchair_accessible for the vehicles that can be boarded for people on wheelchairs, which takes a value of 1. Python scripts were redeveloped to calculate travel time, estimate the number of jobs reached, and to batch estimate AM peak accessibility values for four time thresholds (30, 60, 90 and 120 minutes) at five-minute intervals. In the regression analysis, all the independent variables were joined with average accessibility measurements based on GEOID in a block group boundary level due to available data. Therefore, average accessibility values were merged from block level to a block group level boundary by consolidating all blocks that had the same block group GEOID.

3.4 Data Input

Analysis in this research heavily relied on GTFS data, Latest Open Street Map (OSM), and Open Trip Planner (OTP) tools, other input data sets such as a demographics blocks shapefile as a geographic data, worker population (residence area characteristics), and jobs or employment (workplace area characteristics), DLZ survey for bus stops, etc., were used in transit and walking job accessibility analysis, while disability workers and jobs by place of residence were used for prioritizing bus stops.

3.4.1 General Transit Feed Specification (GTFS) and Modified GTFS Data

General Transit Feed System is a typical structural arrangement for public transportation timetables and interconnected to geographic records, and it is an effectual data source for calculating accessibility in this project. It has 13 text files which form GTFS feed when compressed to a zip file form. The values in each text files are separated by a comma, and each of them contains data regarding agency, routes, stops, timetable, calendar, ticket fares, and frequencies. Each value has a strong relationship from file to file. It can be used it for various purposes along with Google Maps. GTFS is incorporate data for varieties of transportation and multimodal software applications, accessibilities, timetable creation, and mobile apps. In Kalamazoo county GTFS data from K-Metro transit is like a typical GTFS data feed,

various features of transit structural information system, such as stops, routes, trips, and schedules were comprised into a zip txt files. Each text file has some information related to accessibility and travel time measurement. Later on, GTFS data was modified for people with reduced physical mobility based on the GTFS data standard format. GTFS data were expanded especially with regard to accessibility limitation and boarding by wheelchair. Then, a column was added to the field called wheelchair boarding to the GTFS data in the stop.txt file based on the stops survey carried out by DLZ MICHIGAN, INC. GTFS data that was used in this research was obtained from K-Metro and the "Transit App website" (www.transitapp.com).

3.4.2 Open Street Map (OSM)

OSM is a free-access online record dataset of structural network transportation and other spatial information of the world obtained collaboratively from contributors all around the world since it started in 2004 (Yin et al., 2015). Providing detailed network information is different from place to place, such as in urban areas, a much more comprehensive detailed and latest representation of pedestrian networks is provided than at the federal, state, regional, or local sources data. The Open Street Map (OSM) North America data extract, Michigan OSM that was used in this research was obtained from the geofabrik.de website (http://download.geofabrik.de/). The OSM Data describes the pedestrian and road networks in counties, such as the Kalamazoo county area. The modified data in April 2016 from Open Street Map was

used in this project. The pedestrian network is particularly involved with pedestrian features, footways, and residential tags (Owen and Levinson, 2014). The latest OSM for road networks along with GTFS data for transit networks and transit schedules is fundamental to building a graph of the unified pedestrian-transit network for each analysis zone, since OSM data is taken by the Graph Builder module as an input to make street networks.

3.4.3 Geographic Data and Block Shape File

Census block level boundary from the 2010 census are used as the demand locations within Kalamazoo county. Census blocks data are the vital element for travel time calculation and accessibility measurements. Due to core-based statistical areas (CBSAs), the study area was divided into 5,785 blocks as defined by the U.S. Census Bureau. Census blocks and their centroids were the essential units for travel time calculation and accessibility measures. Geographic data such as blocks, tracts, block groups, and places were used from the U.S. Census TIGER 2010 datasets. Block level analysis was preferred because most of the egress trip segments take place by walking. By using the Census block group, travel time calculations may be distorted (Owen and Levinson, 2014). This research used the geographical definitions established for the 2010 decennial census. Accessibility calculations were performed for every block, in a given CBSA, excluding blocks that contained no land.

3.4.4 Workers by Place of Resident and Jobs by Place of Work

The LEHD Origin-Destination Employment Statistics (LODES) are a set of data were published in order to mark the location of employment and workers for most states in the U.S. They were released in almost every year and in small size for analysis, such as block level. RAC represents Residence Area Characteristic data in which jobs are totaled by home census block with h_geocode, while WAC represents Workplace Area Characteristic data in which jobs are totaled by work census block with w_geocode. These datasets contain additional variables such as Race, Ethnicity, Education, and Sex the total population of workers, but these data are only available for data year 2009 and later through a beta release. CR01 is the number of jobs for workers of White only, whereas CR02 is number of jobs for workers of Black or African American only. For the purpose of analysis, Kalamazoo county is extracted from state of Michigan, as workers by place of residence (residence area characteristics as origins) and jobs by place of work (workplace area characteristics as destinations) from the U.S. Census Longitudinal Employer-Household Dynamics (LEHD). Origin and destination are updated annually, providing block-level estimates of employee home and work locations. The LODES dataset for 2013 is the most recent one that was used in this analysis (http://lehd.ces.census.gov/data/).

3.4.5 DLZ Survey

The survey was carried out by DLZ MICHIGAN, INC which was contracted by the Kalamazoo Metro Transit (K-Metro) to collect data on bus stops and shelters for checking compliance with the requirements of the 2010 "Americans with Disabilities Act Standards for Accessible Design" (ADASAD) and to investigate if individual bus stops are connceted to sidewalk (PAR) or not, for prioritizing. The survey was carried out to improve bus stops and make the public transportation service dependable, convenient, cost-effective, safe, and accessible for all and residents of Kalamazoo metropolitant area. The survey was conducted during daylight in the spring and summer of 2014. The number of stations evaluated was 751 unique stops. The data collected include: stop number, presence/absence of boarding platform, platform width, platform depth, platform running slope, platform cross slope, connection to a sidewalk present (pedestrian access route PAR), platform change in evaluation, platform cracks/gaps, presence of obstructions, compliant overhead clearance, presence of protruding objects, presence of bench, space adjacent to bench if present, distance from curb to sidewalk, other items of significance, and compliance with ADASAD.

Furthermore, additional data were collected for stops with shelter. There were 82 stops that had a shelter, except those in the WMU campus that had multiple shelters. Shelter data collection include: stop number, shelter size, connecting to boarding

platform exists, connection to sidewalk present, clear space outside the shelter, clear space inside the shelter, presence of obstructions, other items of significance, and compliance with ADASAD.

Bus stops were evaluated to make sure they were compliant with the ADASAD/PROWAG requirements which include Title II regulation at 28 CFR 25.151 section and 2004 ADA accessibility guidelines (ADAAG). Costs for improvement were also estimated. Based on the survey, only 55 bus stops (7.47% of the total) were fully compliant with ADASAD/PROWAG requirements, and 542 bus stops did not have boarding platforms, which is an issue for disable people, while 72.2% had limited accessibility for disable people. A total of 234 bus stations (31.2%) were not located on a sidewalk (not connected to PAR), which is impossible to access for people with a disability.

4 Methods

4.1 Introduction

This study adopts methods described in Owen and Levinson (2014). This chapter describes the methodology of measuring job accessibility by transit. There are two scenarios: one for people without a disability and the other for people with reduced physical mobility. The only difference for people with reduced physical mobility is modifying GTFS data with wheelchair accessibility for each bus stop. Therefore, the accessibility results are different due to the difference in bus stop accessibility. These parameters were measured by utilizing OTP software and public datasets. Specifically, General Transit Feed Specification (GTFS), Open Street Map (OSM) and Longitudinal Employer-Housing Dynamics (LODES) data were combined with other US Census data and were used to estimate job accessibility for people with constraint mobility.

OTP implements Dijkstra's algorithm by using the shortest path method to calculate a series of origin-destination matrices with transit and walking travel times and distances. Python scripts were developed to batch estimated AM peak accessibility values for four time thresholds (30, 60, 90 and 120 minutes) at five-minute intervals. The methodology was used to prioritize these bus stops based on impact on job accessibility for people with mobility constraints as discussed in Chapter 6. In this chapter, the technique tools and methodology of using the DLZ

survey was used to make a new model of modified GTFS data, and the procedure of calculating accessibility by using analytical tools OTP are described here.

4.2 Technique Tools

4.2.1 Analytical Tools Open Trip Planner (OTP)

Open Trip Planner (OTP) is a multimodal multi-agency trip planning tool written in Java. It is an open-source analysis tool program which has two crucial components: a Graph function component and the Routing component (Yin et al., 2015). The first module OSM is considered as input data to create street and sidewalk networks, along with the GTFS feeding tool, which has the transit schedule and set routes that are released by transit agencies to make transit networks. Subsequently, the two kinds of network traffic are joined into one multimodal transport network, and kept in the Graph that was built. On the other hand, in the second module called Routing, the built Graph is taken as an input, along with user definite parameters such as python script, to conduct Dijkstra's algorithm by using the trees shortest path method to calculate a series of origin-destination matrices that search from a given origin to a given destination, with multi-modal travel times and distances or batch origin/destination (OD) pair analysis. OTP can be obtained at http://opentripplanner.org and is defined in Owen and Levinson (2014). The procedure used to measure accessibility in this project was based on two major steps: calculating travel time in a travel time matrix format and calculating summation of accessibility.

4.2.2 ArcGIS Desktop

ArcGIS Desktop is a software package that is heavily related to geographic information system (GIS). It has an infrastructure used for creating maps, gathering geographic data, and managing, analyzing, sharing and finding out geographic information using maps and geographic statistics in a variety of applications. Sometimes it can be used online The integrated applications for this program cover ArcGIS, with different versions or pro versions, ArcCatalog, ArcMap, ArcScene, ArcGlobe, and ArcToolbox, which can be extended for a number of software programs. In this research, it was extended for uploading GTFS data to create routes and stops map for K-Metro public transit. All the result maps represented in this research were done by ArcMap 10.

4.3 How the Accessibility Information from the DLZ Survey was Used to Modify the K-Metro Standard GTFS Data?

Modifying the GTFS data for people with reduced mobility was started by adding a column for wheelchair boarding in stop.txt and wheelchair accessible in trip.txt file, and running it through OTP, then trying to compare results between data with the wheelchair boarding, and the GTFS data without wheelchair boarding. The data for the wheelchair boarding was obtained from the K-Metro transit agency through a survey that the DLZ Michigan consulting firm conducted. The data acquired was in a Google Earth file format and each stop had specific accessibility

information, such as the connection to pedestrian access route (PAR), presence to boarding platform, and compliance. Furthermore, the consulting firm also conducted a survey for the bus stops, which included a shelter separately as these stops had other standards to account for when compared to regular bus stops. A total of 751 stops and 82 stops with shelters installed were the stops surveyed by DLZ Michigan.

After acquiring these data, a final value (0, 1 or 2) was given to the Wheelchair Boarding column based on the connection to PAR, presence of boarding platform, and the compliance values. Connecting to pedestrian access route and having boarding platform were the major parameters to decide on the accessibility and inaccessibility of bus stops. These values were given based on the General Transit Feed Specification Reference and Standard Format of GTFS data that were compatible with OTP's understanding of the values. To follow is the summary of how these values were accounted for.

4.4 Accessibility values definitions

A. General Transit Feed Specification (GTFS) Reference:

- 0 (or empty) - indicates that there is no accessibility information for the stop
- 1 - indicates that at least some vehicles at this stop can be boarded by a rider in a wheelchair

- 2 - wheelchair boarding is not possible at this stop

B. Data from K-Metro:

- boarding platform present (yes, no)
- connected to pedestrian access route PAR (yes, no)
- compliance (yes, no)

According to the GTFS reference, a zero value was given to stops with no accessibility information, and the same was done to the data provided by K-Metro. A value of 1 according to the GTFS reference was given to stops that had at least some vehicles that could be boarded by a rider in a wheelchair. This was not consistent with what was provided from the K-Metro data; therefore, a value of 1 was given to stops providing both cases, such as providing boarding platform and connected to pedestrian access route (PAR) at least. Connecting to pedestrian access route and having boarding platform were the biggest issues that people with disability faced. Therefore, they were the major parameters to decide on the bus stops that were either accessible for people with reduced mobility or not. If both cases provided but were not in compliance with ADAAG/PROWAG, we could still say that these bus stops were somewhat accessible.

Finally, a value of 2 was given if the wheelchair boarding was not possible at a stop, and the same value was given if boarding platform was not provided or not

connected to pedestrian access route, since these two parameters create limits for accessibility, especially for people with reduced mobility.

Table 4-1 Demonstrates how values were assigned to the accessibility options for the data provided by K-Metro.

Boarding Platform	Pedestrian Access Route (PAR)	Compliance	Value
No Information	No Information	No Information	**0**
YES	YES	YES	**1**
YES	YES	NO	
YES	NO	NO	**2**
NO	YES	YES	
NO	YES	NO	
YES	NO	YES	
NO	NO	NO	

According to the report, GTFS data can be modified for the field of Wheelchair Boarding value (0, 1, 2) based on these categories: First, was boarding platform provided or not, second, was bus stop connected to sidewalk (PAR) or not, and third, were first and second cases for the bus stop compliant with ADAAG/PROWAG or not.

- If both cases provided were compliant, then the bus stop was fully accessible. Value (1) should be considered in GTFS data for wheelchair boarding accessibility. K-Metro GTFS has 55 (7.47%) bus stops fully accessible.

- If both boarding platform were connected to PAR available but not compliant, we put (1) as somewhat accessible for wheelchair accessibility, K-Metro GTFS had 137 (18.61%) bus stops somewhat accessible but they were not compliant with section 810.2 ADAAG appendix F requirements.
- If the bus stops not connected to PAR or has no boarding platform, then it was not accessible. Value (2) should be considered in GTFS data for wheelchair boarding accessibility. K-Metro GTFS had 515 (69.97%) bus stops not accessible.
- K-Metro GTFS has 29 (3.94%) bus stops without information. Value (0) should be considered in GTFS data for wheelchair boarding accessibility.

The pie chart in Figure 4-1 shows the percentage of bus stops in Kalamazoo county that were found to be accessible, not accessible, and has no information about or no data collected by DLZ survey.

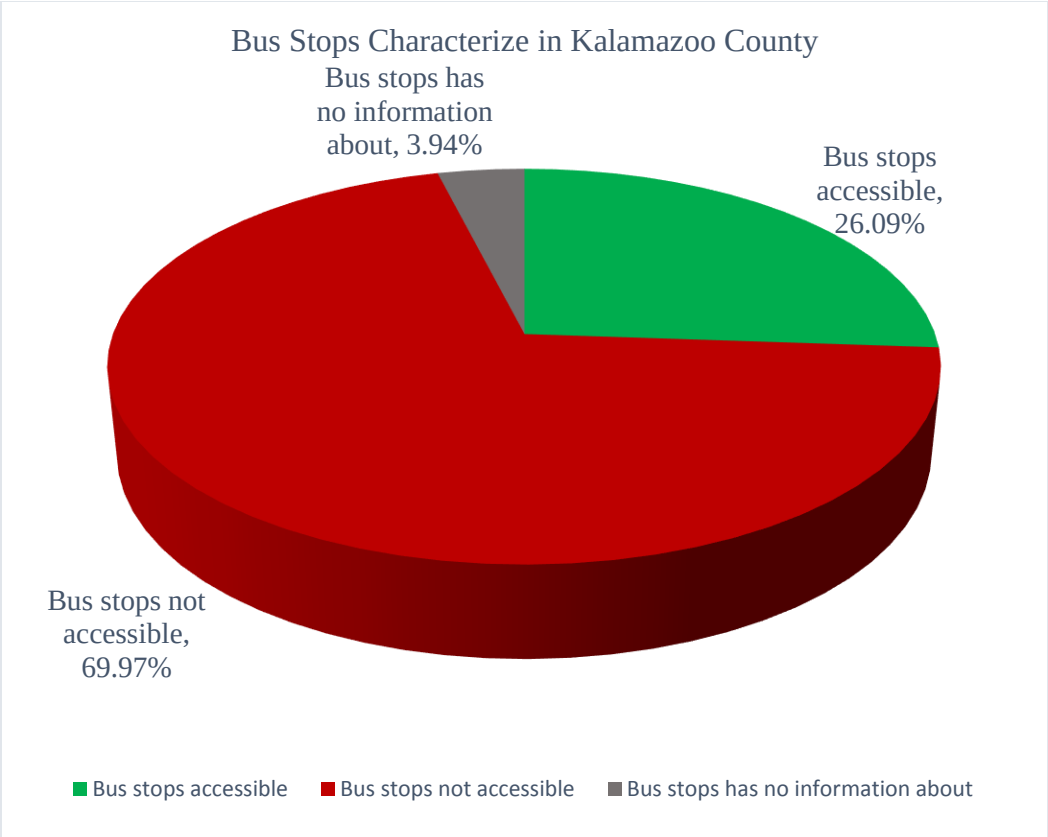


Figure 4-1 Bus stops accessibility information for people with limited physical mobility in Kalamazoo county.

4.5 Analytical Tools Open Trip Planner and Procedures Used to Calculate Accessibility

As mentioned in Yin et al. (2015), accessibility measures can be broadly categorized into four classes: opportunity, gravity, utility, and space-time based. In my research, transit and walking job accessibility was calculated which was opportunity-based. It means how many job opportunities can be seized via transit and walking. It related to the same approach as described in Owen and Levinson (2014).

By access utilizing Open Trip Planner (OTP) software and public datasets, specifically, General Transit Feed Specification (GTFS), Open Street Map (OSM) and Longitudinal Employer-Housing Dynamics (LODES) data were combined with other US Census data and were used to estimate job accessibility for both people with and without constraint physical mobility. Open Trip Planner (OTP) implements Dijkstra's algorithm by using the trees shortest path method to calculate a series of origin-destination matrices with multi-modal travel times and distances. Python scripts were developed to batch estimate AM peak accessibility values for four time thresholds (30, 60, 90 and 120 minutes) at five-minute intervals. The detailed steps for this analysis are shown below.

First of all, by using Open Trip Planner (OTP) software, which has a graph building function, travel time and walking distance were calculated in this project, based on the analyzing GTFS data and using the Open Street Map (OSM) with public datasets to generate a transit network (Graph builder). Timetable and transit networks in K-Metro GTFS feed format with street and pedestrian network data from Open Street Map were combined by access, utilizing OTP through the unified graph building process. The GTFS data included a total of 736 stops for the K-Metro transit agency in Kalamazoo county. To begin with, for measuring general job accessibility, GTFS data did not include a wheelchair_boarding field data, which was limited to the stop id, stop name, latitude, and longitude. GTFS data along with the Kalamazoo county Open Street Map (OSM), US Census such as block level and block centroid,

and other relevant files were run through OTP using a python script file that was used to build graphs and calculate the Travel Time Matrix. The python script utilized with OTP had some limitation and requests for calculating travel time such as set a limit to a maximum travel time of 2 hours in the selected area because it is a time-based process. Also, multimodal transport mode was defined, such as WALK, BUS, etc and a set departure time for every departure time of 5-minute intervals from 7 to 10 am during the peak period. For each analysis zone, a graph was built which has a relation to the transit timetable. OTP read the point's destination from a points.csv file to calculate travel time and walking distance for each census block as the origin to all other blocks as a destination within a two-hour limit for the selected county from departure time. The final output was a Travel Time Matrix for Kalamazoo county describing the origins, destinations, walking distance, and the travel time. The next steps depended on the graph-generated process and travel time matrix joined with worker by place of residence as an origin demand file, and jobs by place of work as a destination locations file, to make only one analysis package, which had all the data needed to measure accessibility values for the blocks level in the study area. Later, the same process was repeated for workers with reduced physical mobility by modifying GTFS data. The process added a column called Wheelchair Boarding, and running it again through OTP, and finally trying to compare the accessibility results. The data for the Wheelchair Boarding was obtained from the K-Metro transit agency through a survey that the DLZ Michigan consulting firm conducted.

In the second step, calculating transit and walking job accessibility for both workers with reduced physical mobility and those without was started after the graph and travel time matrix were generated. Therefore, accessibility measurement depends on the travel times that were measured from each census block centroid on a comprehensive transit timetable from GTFS data, with street and pedestrian networks from OSM combined with Longitudinal Employer-Housing Dynamics (LODES) data, combined with other US Census data, and were used to estimate job accessibility. A summary of variable outcomes was defined in the second step for all points as summation walk distance, summation boardings, summation travel time, summation network access, and measuring summation job opportunity accessible for ridership with disability, by using modified GTFS data, and without disability wheelchair boarding, with normal GTFS data. Python scripts were generated to batch estimate AM peak accessibility values for four time thresholds (30, 60, 90 and 120 minutes), for no more than a two-hour travel time based on repeated travel time calculation for each block and every departure time as a loop at five-minute intervals departure time. This counted 12 times within an hour for three-hour limit, during the peak period time on a weekday transit normal working day, between 7 and 10 AM. Then, average job accessibility was calculated for all departure times, to show the number of jobs that were accessible, on average, in travel time thresholds mentioned before. A thematic/choropleth map of the summary data was made by using block boundaries data to show percentage of jobs accessible and making a comparison

based on this result for unlimited and limited accessibility for people with reduced mobility. The colored measurement area was then weighted by the number of workers residing in each census block and averaged crosswise the entire Kalamazoo county area to produce job-weighted accessibility. The purpose of this measurement was to show the percentage of jobs accessible and difference of transit and walking job accessibility as a percentage, based on the result for unlimited and limited accessibility for people with reduced mobility. Block level is preferred rather than the block group level, and provided an important increase in spatial determination, which is essential because most of the egress trip segments take place by walking, and pedestrian speeds are low-relevant to the block group size in the majority of transit access, and therefore, travel time calculations may be distorted.

5 Analysis of Accessibility

5.1 Introduction

In this chapter, first of all, the terminologies and variables that best define the results are described here. Then, the walk and transit mode accessibility result evaluation and comparison are shown between both transit accessibility result data sets, with limited physical mobility (Case Two) and without (Case One), to show the reality of the problem disabled people face every day, and their effects on accessibility reduction.

5.2 Terminologies and Variables

From a transportation planning perspective and in order to simplify the discussion, the terminologies which were used in this research and the variable outputs are defined as follow:

5.2.1 Terminologies

- Accessibility measurement: Conducting of an accessibility measure or the process of measuring job accessibility, which is called average network access in this research.
- Multimodal Accessibility: Using a multimodal transport network such as a side walk, roads, railways, ferry channels or air routes, which include using multiple modes of transport such as walking, bus, ferry, train, plane, etc. (Farber et al., 2014).

- Wheelchair boarding: Refers to these bus stops that can be accessible for people with a wheelchair. Therefore, people with a disability can be boarded by some vehicles that can carry people who use a wheelchair.
- Wheelchair accessible: Refers to these vehicles that at least can board one person with a wheelchair.

5.2.2 Variables

Python scripts were developed to estimate job accessibility via transit and walking in Kalamazoo county through OTP. The transportation performance measures estimate cumulative opportunities achieved for each of the 5,785 census blocks in Kalamazoo county within specific travel time thresholds (30, 60, 90 and 120-minutes). Accessibility formulas were coded in the python script, to calculate the following variable outputs:

(a) The number of destinations (i.e., census blocks with jobs) reached from each origin

Equation 1

$$D_i = \sum_j D_j f(C_{ij})$$

where i and j represent origins and destinations, respectively and D_i is the sum of total employment destinations reached from origin i within a given travel time threshold, $f(C_{ij})$. Following Owen and Levinson (2014), cumulative opportunities Equations 1-4 employ a binary weighting function, such that:

$$f(C_{ij}) = \begin{cases} 1 \ if \ C_{ij} \leq t \\ 0 \ if \ C_{ij} < t \end{cases}$$

t=travel time threshold

(b) the number of transit boarding (i.e., the number of transfers plus one) needed to get from each origin to each destination.

Equation 2

$$B_i = \sum_j B_{ij} f(C_{ij})$$

Where B_i is the sum of total public transit boardings needed to reach destination j from origin i within a given travel time threshold.

(c) the sum of jobs located within reached destinations.

Equation 3

$$A_i = \sum_j W_j f(C_{ij})$$

where A_i represents the total number of jobs or employment opportunities accessible from origin i to employment destinations, W_j within a given travel time threshold.

(d) the total number of jobs located within reached destinations with jobs weighted using a nonlinear, distance decay function.

Equation 4

$$AW_i = \sum_j W_j \exp(C_{ij})^{-0.08} f(C_{ij})$$

where AW_i represents the total number of weighted jobs or employment opportunities accessible from origin i to employment destinations, W_j. Equation 4 employs the exponential distance decay function, $\exp(C_{ij})^{-0.08}$ to inversely weight the value of employment opportunities with respect to travel time. While it has become

conventional wisdom that distance (and/or travel time) is a major factor that influences the perceived value of opportunities (including employment), this study employs a relatively weak distance decay parameter of -0.08 to avoid overstating the effect of travel time on the desirability of employment opportunities.

5.3 Accessibility Results and Evaluation

The accessibility results and evaluation is the most significant part of this project, to show the accuracy of this research. In the original case, reduced physical mobility workers who use a wheelchair were not considered in measuring job accessibility by transit. In the second case, reduced physical mobility workers who use a wheelchair were taken into account in measuring job accessibility by transit, due to the problems facing people who use a wheelchair in Kalamazoo county, in order to find a suitable solution for increasing transit job accessibility for them. The accessibility results and evaluation for both cases—people without reduced physical mobility (Case One) and with reduced physical mobility (Case Two)—are shown in Appendix B and C in detail respectively. Also, the third case result, after selecting some bus stops for improvement to solve Case Two problems efficiently and economically is presented in the Appendix D. The results are composed of the average network access (job accessibility), average travel time, and average walking distance, which are represented by utilizing the thematic map option in ArcGIS software package. Moreover, the total number of boarding and job opportunities that

can be reached were estimated over all of Kalamazoo county by utilizing bar chart diagrams as shown in comparison between the Case Two scenario. The analysis results were conducted for four time thresholds (30, 60, 90 and 120 minutes) at five-minute variation in frequency in AM peak period time from 7 to 10 AM but only the 60-minute time limit job accessibility as an average were represented here for the other time limits can be seen in Appendix B and C in detail.

5.4 Average of Network Access (Job Accessibility)

Job accessibility is one of the main components of accessibility results in all cases. The average of summation network access represents the total number of weighted jobs or employment opportunities accessible from each origin to multiple employment destinations. A nonlinear, distance decay function was used to represent the total number of jobs located within reached destinations with jobs weighted. The average of summation network access is characterized in the thematic map quantile option through ArcGIS software package for 60-minute time thresholds for both Case One and Case Two as an average time limit as shown in the Figure 5-1. The highest color density per category, which has an equal number of blocks inside, represents the highest access to jobs in those blocks. It means less travel time and walking distance required from the point of origins. As shown in the results, those blocks which have more accessibility to jobs are located near bus route networks in downtown Kalamazoo and Portage, and some other townships. The (Avg_PCTTable) were

presented as average jobs that are accessed from each origin census block as a percentage of total jobs in the county. The weighted values were fewer for Case Two, compared to Case One due to inaccessibility bus stops. Percentage of reduction in Case Two were shown in comparative sections for each block boundary.

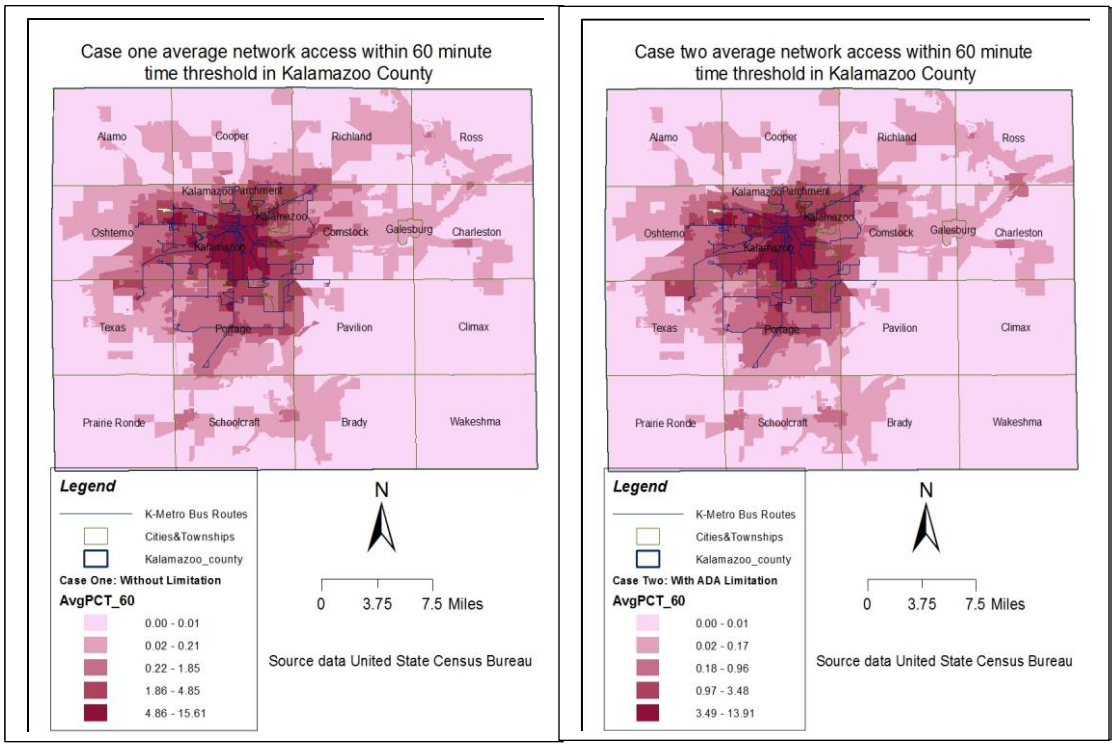


Figure 5-1 Average of network access for 60-minute time threshold without and with wheelchair boarding consideration in Kalamazoo county.

5.5 Comparison Between Accessibility Results of Case One and Case Two

This section provides evidence that inaccessible bus stops in Kalamazoo county is a real problem, which has been faced by workers with physically reduced mobility, and especially for people who use a wheelchair. It denotes how transit job accessibility measurement decreased while wheelchair boarding was taken into account in bus stops in Kalamazoo county. The comparison was conducted for all result sections, after running OTP. Some differences are represented by a bar chart over all Kalamazoo county, such as number of boarding and job opportunities that can be reached through public transit and walking in the study area. The other differences are represented in block level boundary such as average accessibility to network access, travel time, and walking distances to show accurately how inaccessibility affects these bus stops in the study area in developing business, job opportunity, and independence of disabled people. Therefore, the percentage of reductions or differences for each output variable can be defined as a problem faced by disabled workers. Differences and percentage of reduction of number of jobs, network accessibility, or job accessibility, and number of boarding is shown in the following sections, but percentage of differences in travel time and walking distance can be seen in Appendix E.

5.5.1 Difference in Total Number of Jobs

The difference between total number of job opportunity which can be reached by workers through public transit or walking that were measured for both cases in the AM peak period time from 7 to 10 AM at five-minute intervals, over all Kalamazoo county. In the first case, normal wheelchair boarding was not considered while in the second case, wheelchair boarding was considered. The difference in the number of jobs reached were shown for four time thresholds (30, 60, 90 and 120 minutes) by bar chart diagram in the Figure 5-2. It is clear that number of job opportunities reachable decreased dramatically from 5978, 28815, 53364, and 67549 to 5122, 22659, 44530, and 61683 jobs, so the percentage of reduction was 14.32%, 21.36%, 16.55% and 8.68% for 30, 60, 90, and 120-minutes threshold time respectively overall Kalamazoo county, due to inaccessibility of 70% of bus stops in the area.

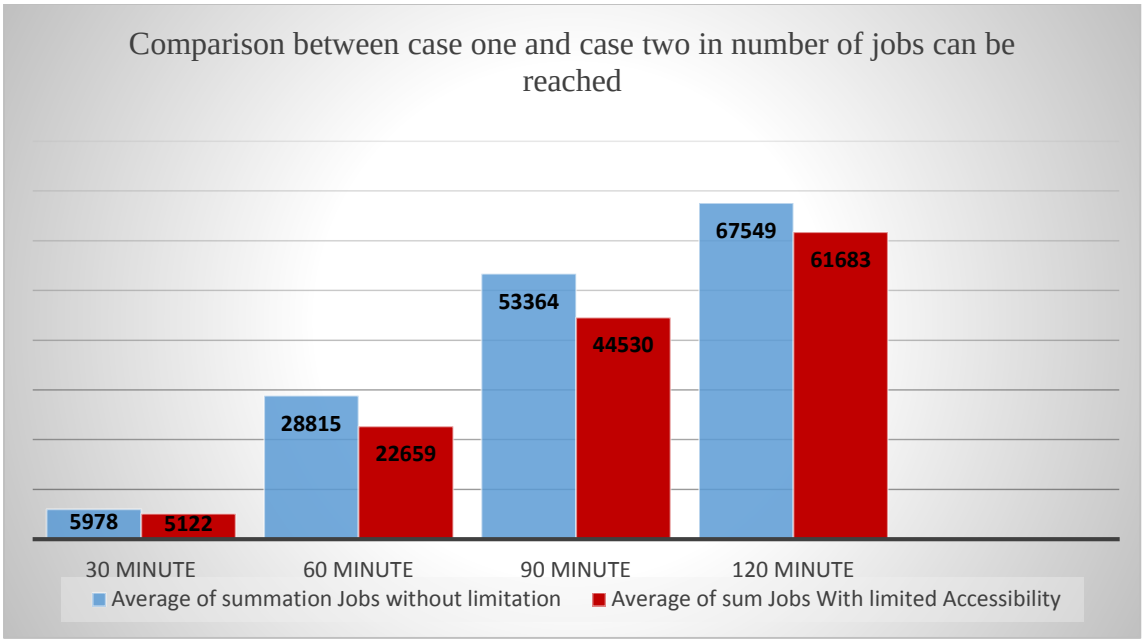


Figure 5-2 Comparison between Case One and Case Two in number of jobs reachable.

In 60-minute or one-hour time thresholds, which is more common for one time transfers between bus routes and travel time in Kalamazoo county, it shows the highest percentage of reduction between both cases, which is about 21.36% summation of jobs less accessible for people with reduced physical mobility via transit and walking, which influences their freedom and independence in their lives, as compared to others.

5.5.2 Difference in Average of Network Access (Job Accessibility)

The difference on average of summation network access for workers who have access to the network or jobs is represented in block level boundary by thematic

map quantile option through ArcGIS software package, for each 30, 60, 90, and 120-minute time threshold as shown in the following figures. The differences in accessibility were calculated for the original data before being uploaded to the ArcGIS program. In Case One, wheelchair boarding was not considered, while in Case Two, wheelchair boarding was considered, and accessibility measurement decreased significantly as shown in the figures per block level. The highest color density per category which has equal number of blocks represents the highest percentage of reduction in job access. The 30-minute time threshold shows Kalamazoo and Portage and some townships have a big difference in accessibility for Case Two as compared to Case One. Also, Oshtemo, Texas, and Comstock Townships partially participate in this reduction in accessibility as shown in Figure 5-3. In 60, 90, and 120-minute time thresholds, the highest difference goes to outside of the network and the Kalamazoo city center. Generally, the big difference appears in Comstock, Cooper, Oshtemo, Texas, Portage, Pavilion, and Schoolcraft Townships, however, a few reverse differences happened in a small number of blocks as shown in Figure 5-4, Figure 5-5, and Figure 5-6. Overall in Kalamazoo county, the percentage of reduction in summation network access due to 70% inaccessibility of bus stops are 15.55% in 30 minute, 25.98% in 60 minute, 28.68% in 90 minute, and 28.86% in 120-minute time thresholds.

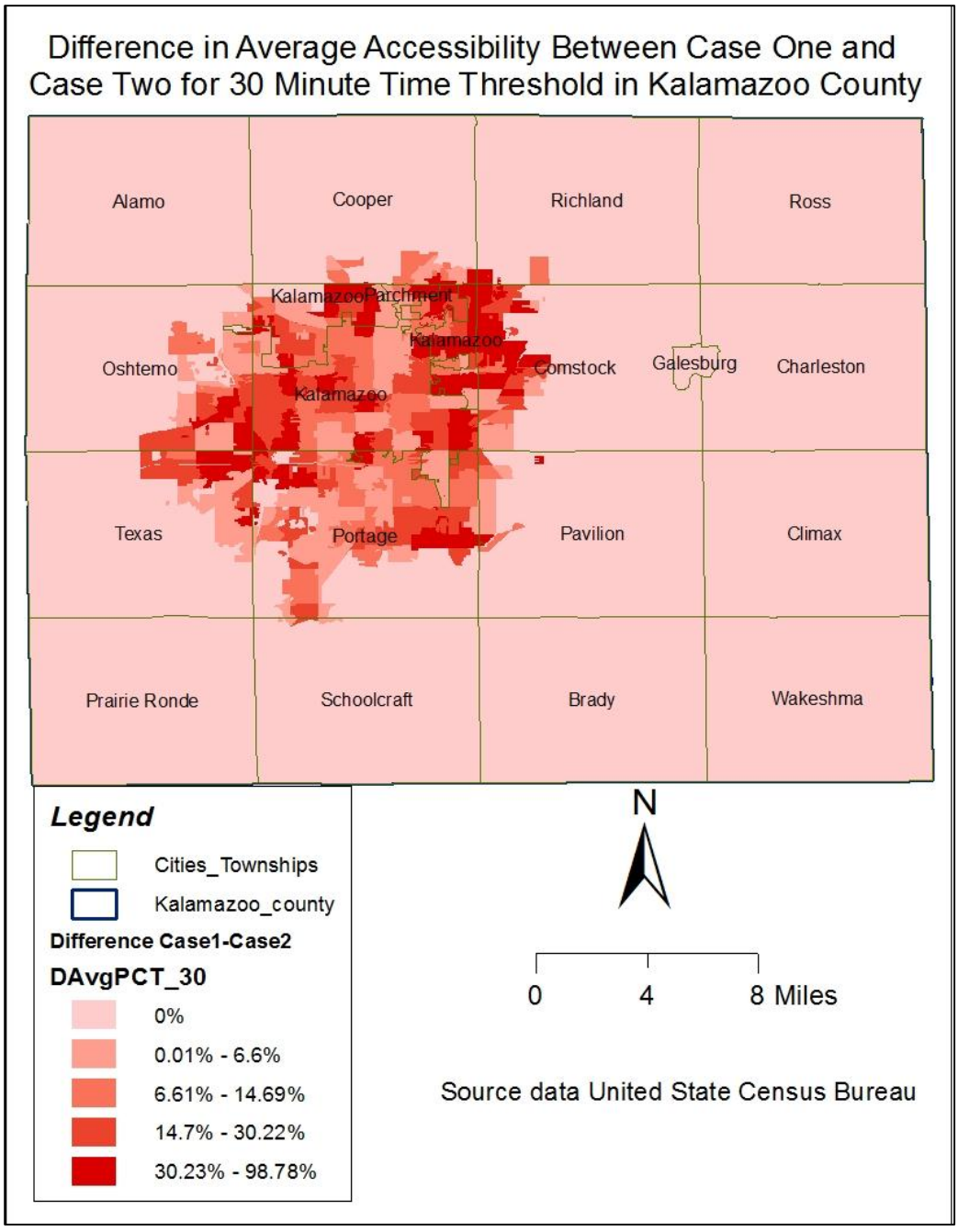


Figure 5-3 Difference in average network access for both Case One and Case Two within 30 minute in Kalamazoo county.

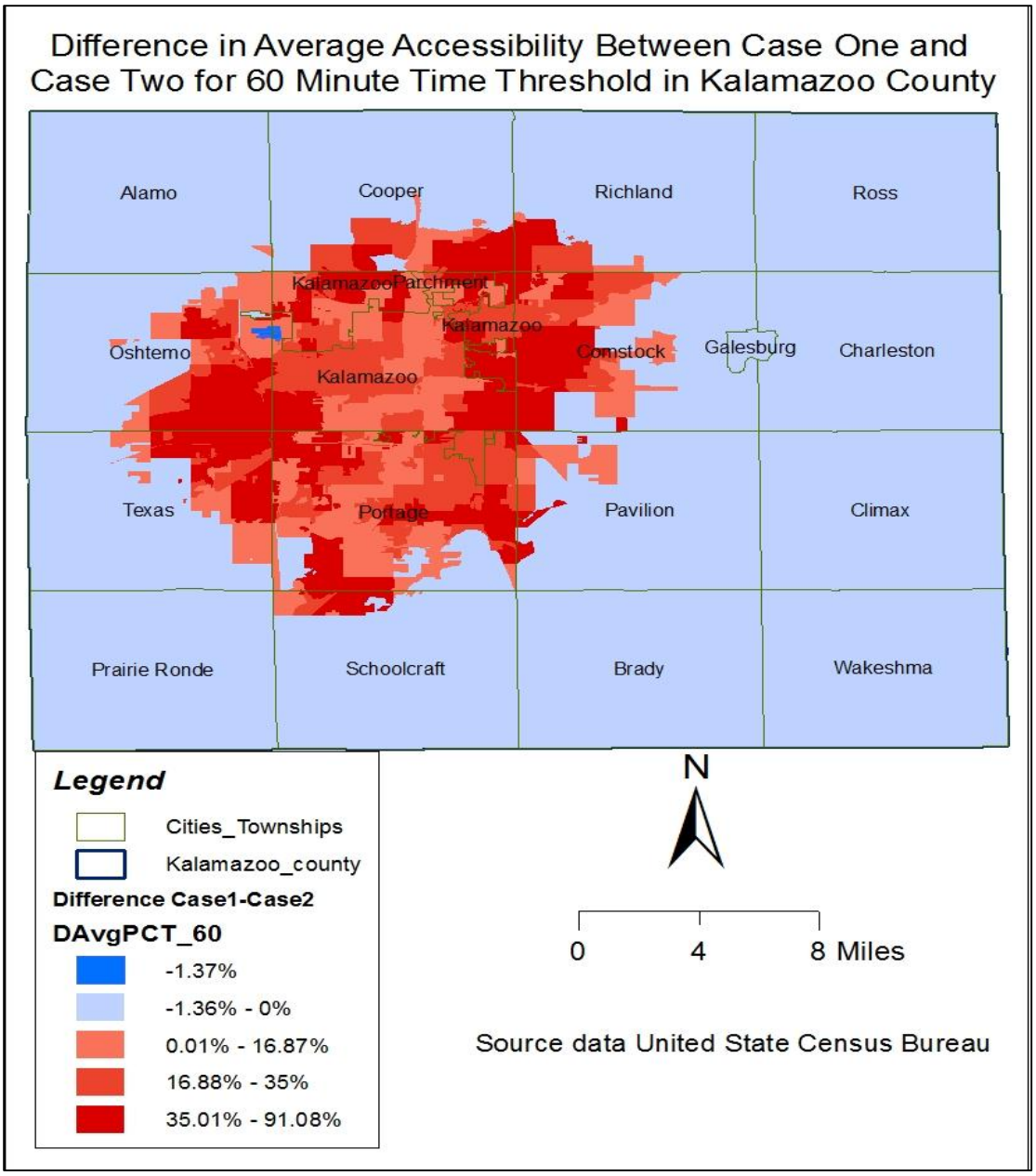


Figure 5-4 Difference in average network access for both Case One and Case Two within 60 minute in Kalamazoo county.

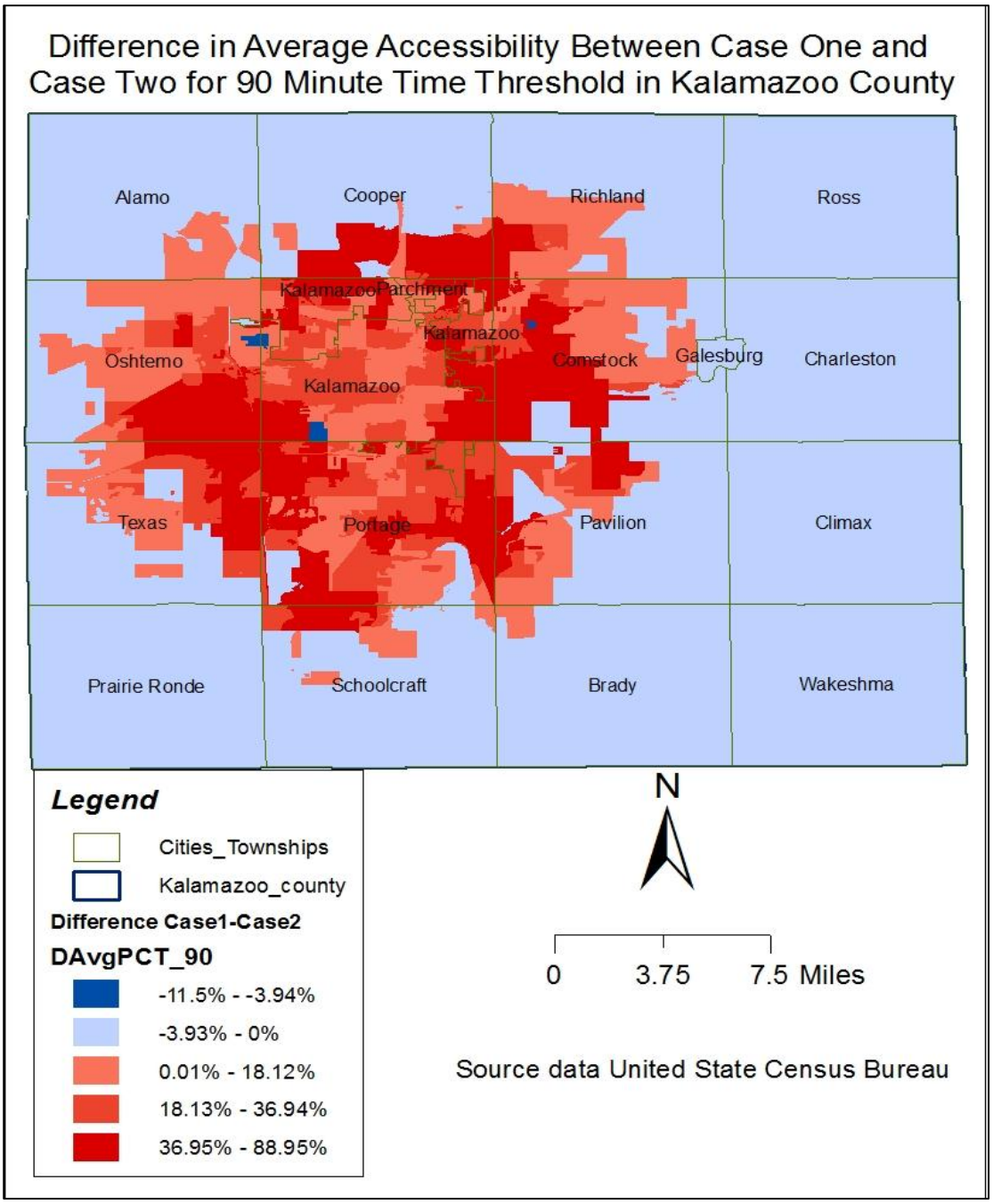


Figure 5-5 Difference in average network access for both Case One and Case Two within 90 minute in Kalamazoo county.

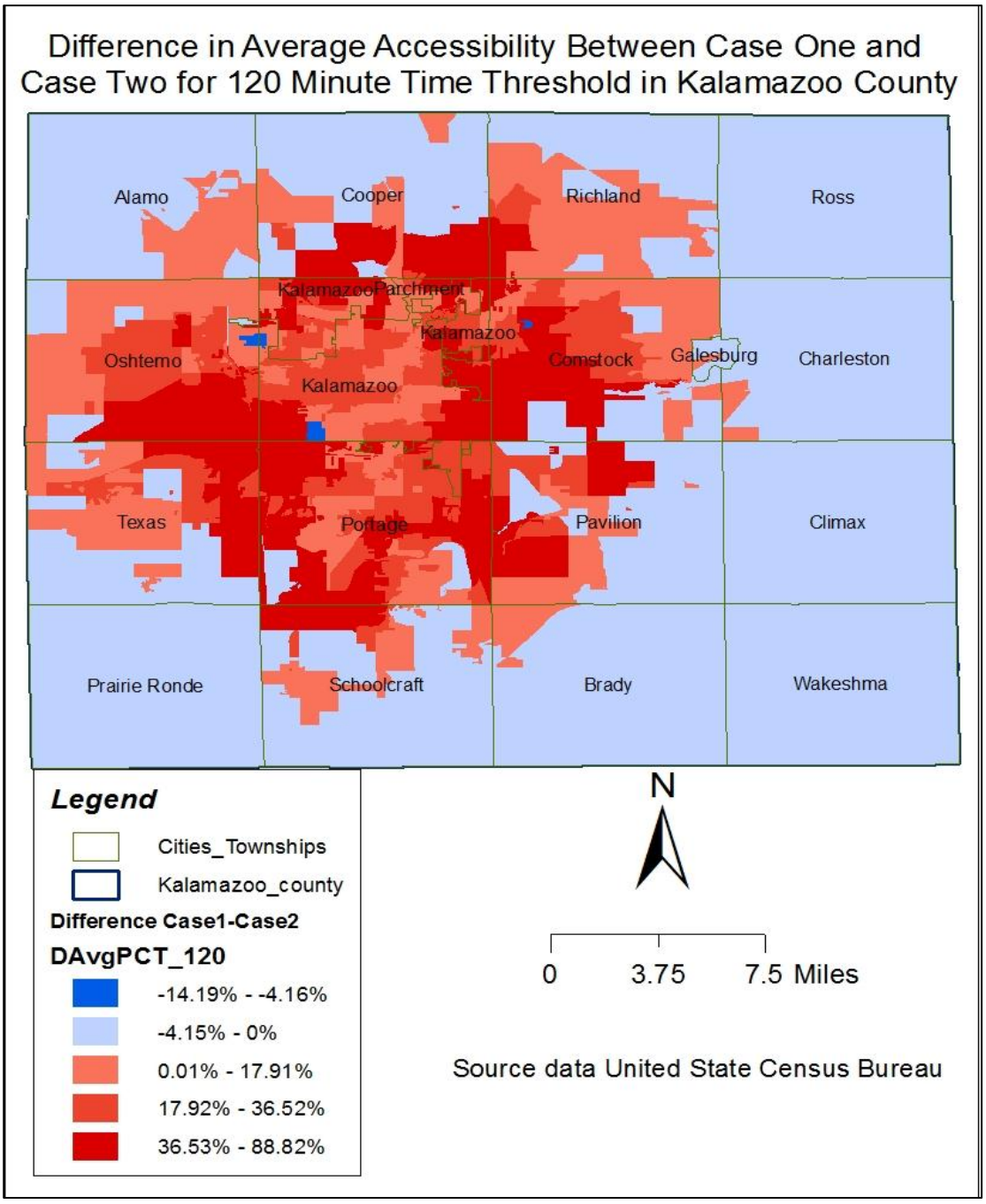


Figure 5-6 Difference in average network access for both Case One and Case Two within 120 minute in Kalamazoo county.

5.5.3 Difference in Total Number of Boarding

The number of transit boarding (i.e., the number of transfers plus one) is a number of boarding required to get destinations, from each origin for each transit rider. The number of boarding decreases due to inaccessibility of bus stops. As clarified before, due to the DLZ survey, about 70% of bus stops were found to be inaccessible in Kalamazoo county, which has a huge impact on accessibility measurement and number of boarding in the study area. In Case One, due to not considering wheelchair boarding, all bus stops were fully accessible. Therefore, the number of boarding is high. Since wheelchair boarding for people with physically reduced mobility were taken into account due to limited accessibility, these numbers decreased dramatically in Case Two. The differences are summarized by a bar chart diagram in Figure 5-7.

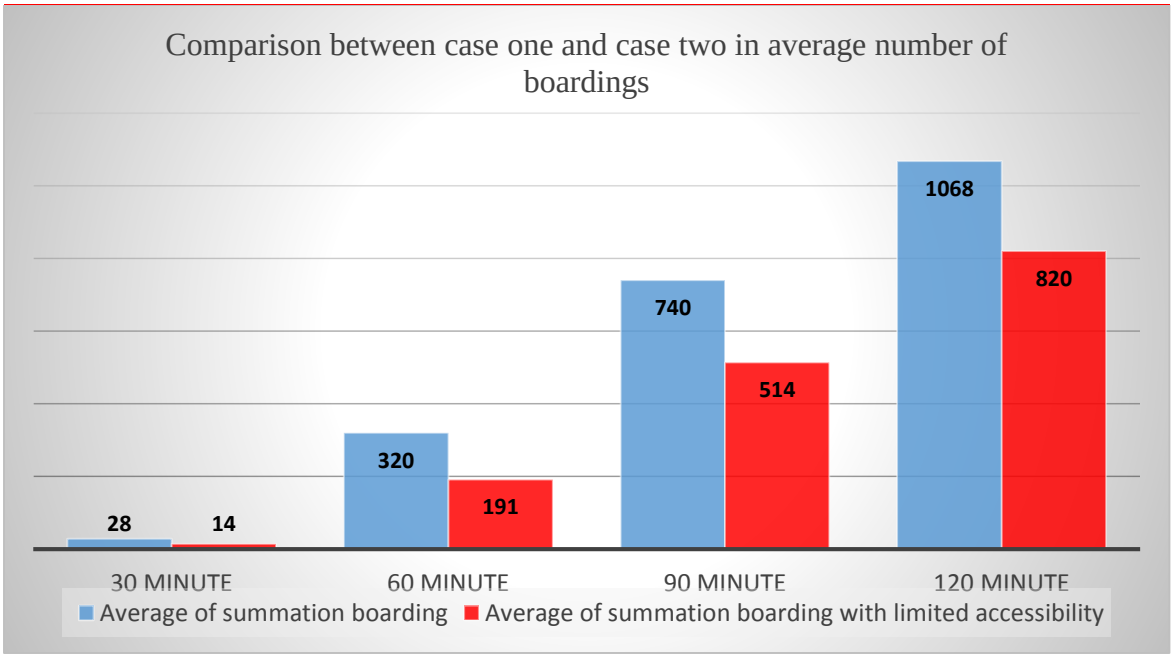


Figure 5-7 Difference between summation of boarding for Case One and Case Two.

As it is clear that the number of boarding decreased from 28 to 14 in 30 minute, 320 to 191 in 60 minute, 740 to 514 in 90 minute, and 1068 to 820 in 120-minute in four time thresholds respectively when wheelchair boarding is taken into account. Therefore, the number of boarding reduced as a percentage of 50.0% in 30 minute, 40.31% in 60 minute, 30.54% in 90 minute, and 23.22% in 120-minute time thresholds, so the influence or percentage of reductions are big enough to think about a solution for this problem. Therefore, the next chapter a method is proposed to solve a percentage of this problem.

6 Improvement of Inaccessible Bus Stops

6.1 Introduction

This chapter is a significant chapter, which points to the solution of the problems that are faced every day for disabled workers in Kalamazoo county. In this chapter, inaccessible bus stops were selected, which have a big influence on increasing job accessibility for people with mobility constraints. Therefore, it is urgent that the bus stops be improved to provide better job access. The methodology used to prioritize these bus stops depends on three variables. These variables were disabled worker locations, job locations, and locations of bus stops which are not accessible. The process starts by matching them on ArcGIS package program to find the location of inaccessible bus stops that are located in dense area of disabled workers and jobs locations. The detailed descriptions for this approach and methodology are clarified in the following sections.

6.2 Procedure Used to Prioritize Improving Bus Stops

The approach used to prioritize the retrofitting of those bus stops which need to be improved would have a huge impact on improving accessibility and percentage of reduction of job accessibility for people with reduced physical mobility and this was conducted by ArcGIS program. First of all, the shape file for those bus stops which are not accessible for people with disability was extracted from the total bus stops in the GTFS data for Kalamazoo county. Due to the DLZ Michigan survey,

selecting those bus stops which are not accessible are based on two major requirements. The requirements that make it difficult for people with disabilities are composed of: (1) not connecting to pedestrian access route PAR, or (2) not providing boarding platform for the bus stops. These bus stops are matched with the input census data of people with a disability as shown in Figure 6-1 and jobs by place of work as destination as shown in Figure 6-2, which are mapped by thematic map. In the ArcGIS program quantile thematic map, 18479 workers with a disability showed in 189 block group boundary level. The maximum number is 330 and minimum 0 disabled worker in block group with mean 97.77, median 82, and standard deviation 64.35. Therefore, the block group had a dense area with the range of 153 to 330 workers with a disability, and were selected as the highest density areas. The range of 153 to 330 disabled workers' selection were based on ArcGIS quantile method in thematic map.

Quantile thematic map for a total 113,706 jobs by place of work were done in total 5,785 block boundary level in Kalamazoo county. The maximum number is 5,474 and minimum 0 jobs in a block with a mean value 19.66 and standard deviation is 143.17. Therefore, the block level with a range from 54 to 5474 workers inside were selected as a highest density. Those inaccessible bus stops again were chosen to be improved that were located in the highest density job locations in the thematic map. About 58 inaccessible bus stops were common, i.e., located in both origin and destination data. These selections are effective to serve the highest number of

disabled worker connected to the largest number of jobs available in Kalamazoo county. As such, accessibility for the highest number of jobs would increase for people with a disability.

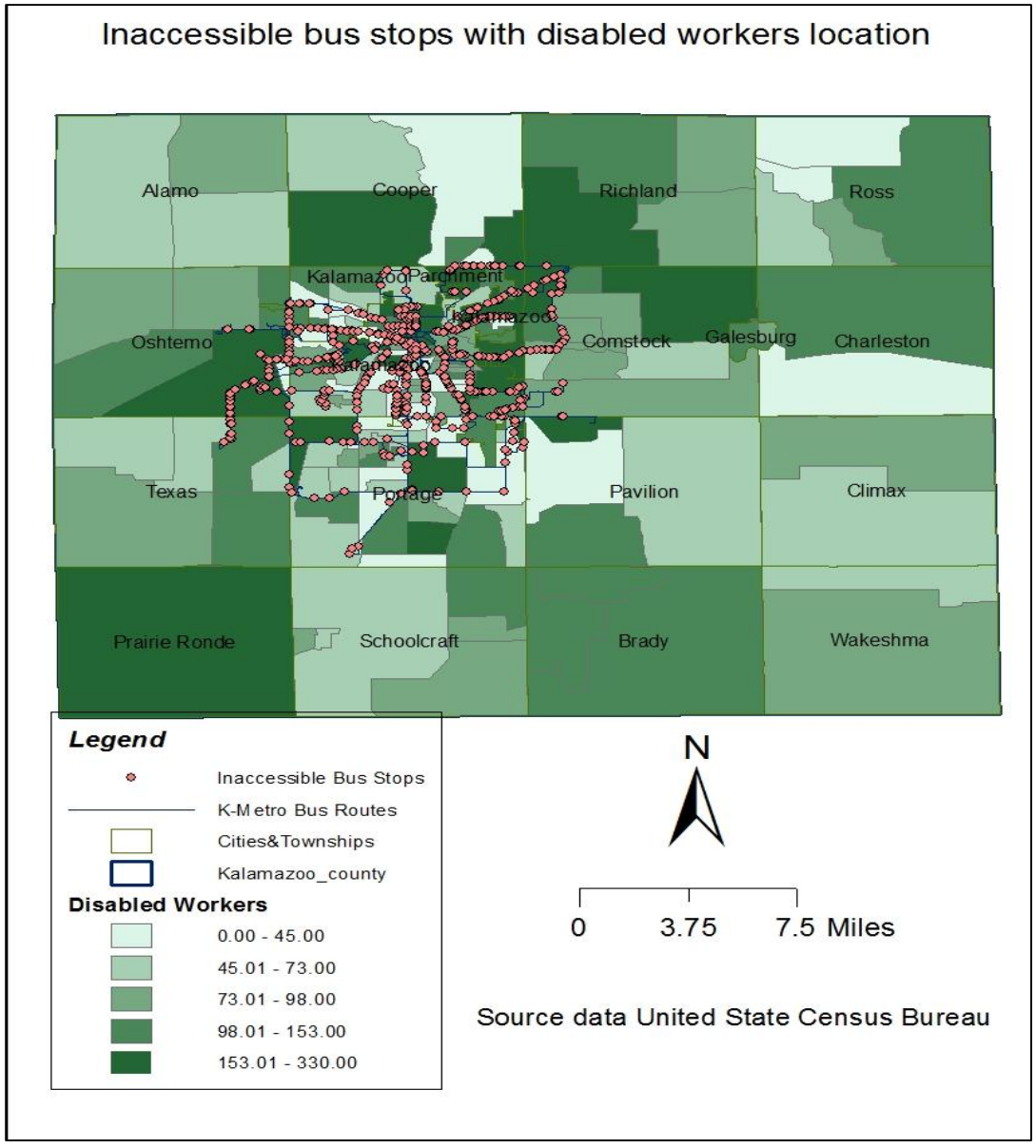


Figure 6-1 Matching inaccessible bus stops with disabled workers' location.

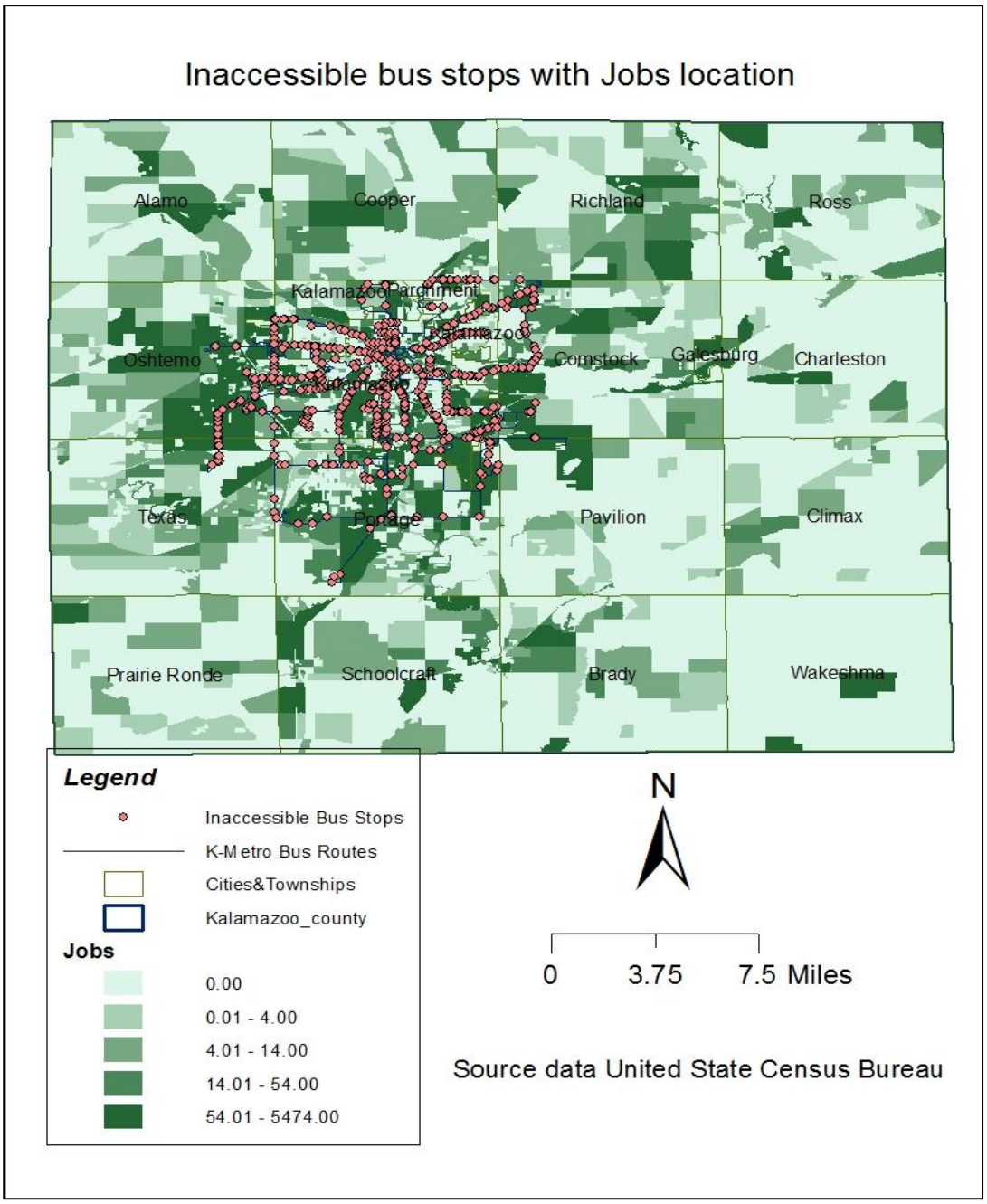


Figure 6-2 Matching inaccessible bus stops with dense area jobs locations.

Finally, 290 bus stops were selected for improvement, of which 180 were inaccessible bus stops located in dense areas of disabled workers as origin of the trip, as shown in Figure 6-3 and 168 inaccessible bus stops were located in dense areas of jobs location as destination of the trip as shown in Figure 6-4. About 58 bus stops were located in both origin and destination; therefore, they could not be calculated twice to avoid duplication. Therefore, as a total 290 inaccessible bus stops were selected for improvement. The ID and cost estimations per each bus stops are shown in Appendix A. The selections were cost-effective manner or economically based because the estimated cost for improving those bus stops was around one third of the total cost.

After finding these bus stops needed to be improved urgently, another model was made for GTFS data called After Improvement by modifying wheelchair_boarding again in the stops.txt file by changing the value of inaccessible bus stops that were selected in the above process from value 2 to value 1. Value 2 indicates inaccessible while value 1 shows accessible. After that, OTP was run again in the same process for Case One and Case Two to make Case Three show the result of the improved bus stops, in order to make a comparison with Case Two to demonstrate how the influence on accessibility improves values after improvement of these bus stops. The percentage of increments is clarified in the comparison section.

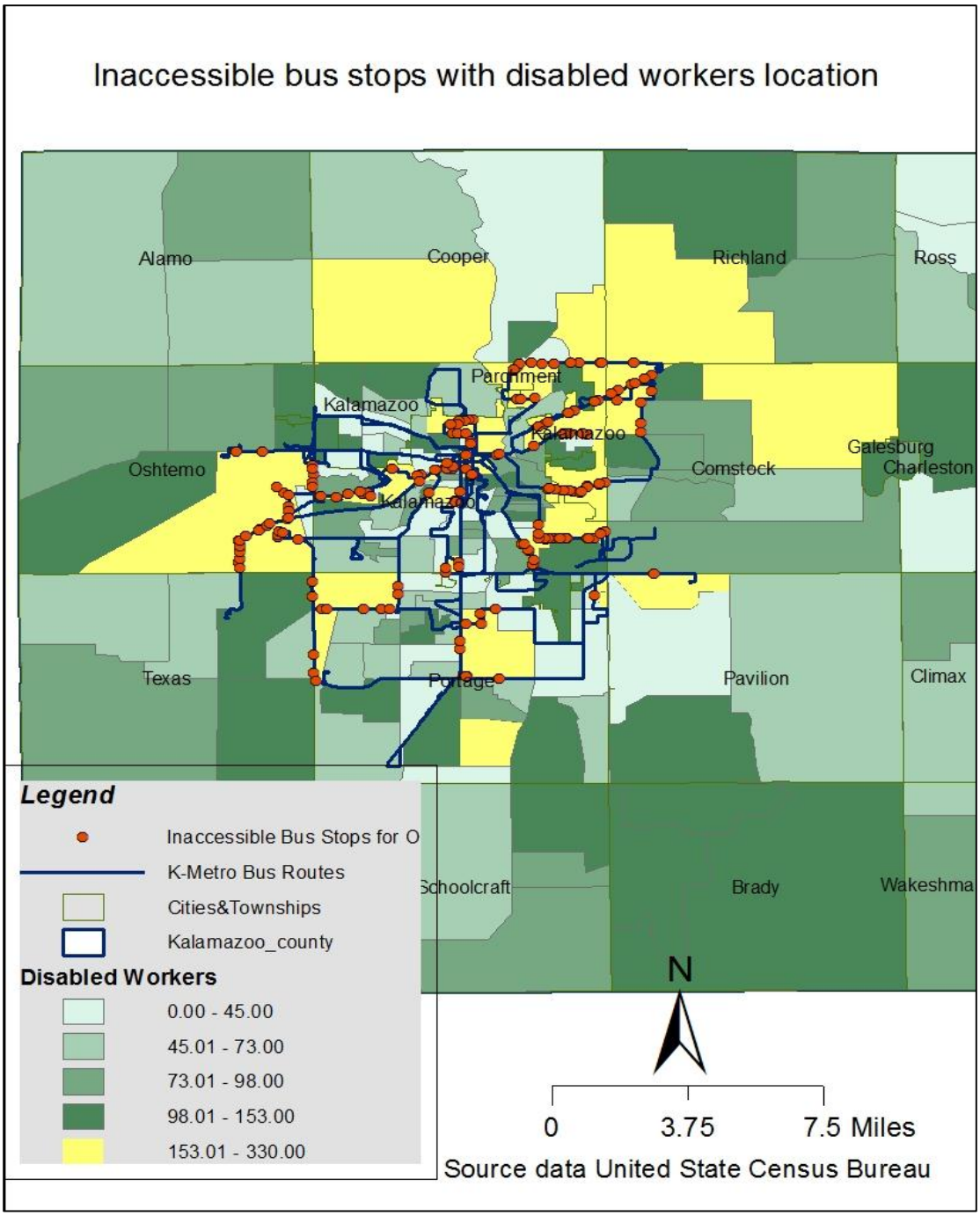


Figure 6-3 Inaccessible bus stops located in dense area of disabled workers.

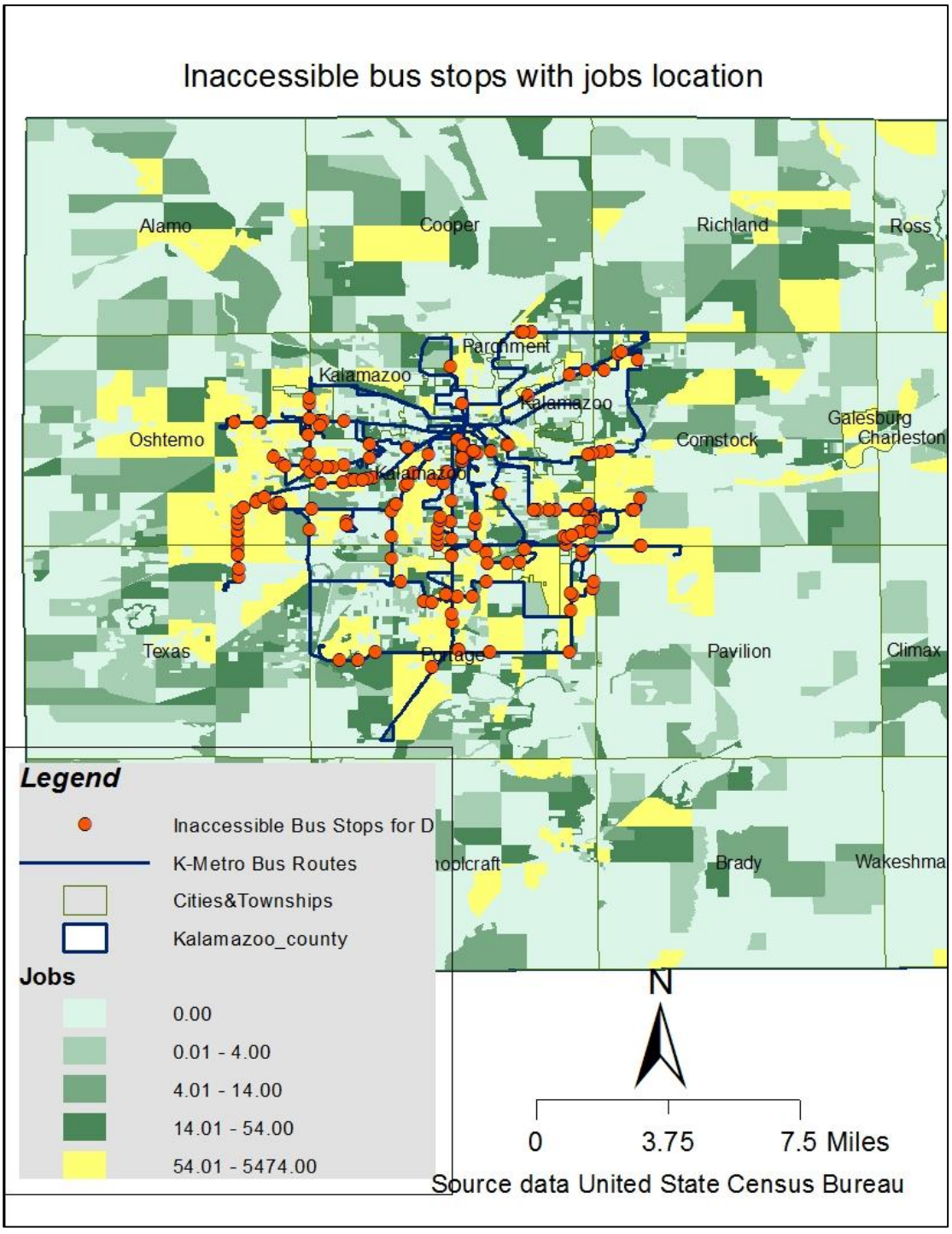


Figure 6-4 Inaccessible bus stops located in dense area of jobs.

6.3 Case Three Results: (After Improving Prioritized Bus Stops)

After efficiently and economically prioritizing the improvement of these inaccessible bus stops based on the origin and destination dense areas to solve the ridership problems disable workers have been faced with in Kalamazoo county regarding transit use and independence, the problem appears in Case Two results by looking at number of job opportunity and accessibility reduction, where percentage of reduction was defined as the problem after improving 180 bus stops in origin and 168 bus stops in destination. Totally, 290 bus stops out of 515 inaccessible bus stops equal to 56.31% of totally inaccessible bus stops were selected for improvement without duplication to show at what percentage the defined problem can be solved. Those selected inaccessible bus stops were modified in GTFS data to make them accessible and therefore, OTP was run again. The results were obtained showing an excellent improvement, which are represented as average summation of jobs, job accessibility or average of summation network access, average of summation boarding, average of travel time, and average of walking distance as shown in Appendix D consequently. These measurements were done for four time thresholds (30, 60, 90 and 120 minutes) at five-minute intervals from 7 to 10 AM, over all Kalamazoo county. A five-minute interval was selected to better differentiate between transit travel time components.

6.4 Job Accessibility or Average of Network Access After Improvement

The average of summation network access represents the total number of weighted jobs or employment opportunities accessible from each origin to multiple employment destinations. The highest weight of access was given to the closest jobs. A nonlinear, distance decay function was used to represent the total number of jobs located within reached destinations with jobs weighted. The average of the summation network access is characterized in the thematic map quantile option through ArcGIS software package for each 30, 60, 90, and 120-minute time thresholds as shown in the Appendix D. The 60-minute time limit as an average is shown in Figure 6-5. In all cases, wheelchair boarding was considered for measuring accessibility but those inaccessible bus stops were selected for improvement were modified in GTFS data. Therefore, network accessibility increased more than that of Case Two. The highest color density per category which has an equal number of blocks represents the highest access to jobs. As shown in the results, those blocks which have more access to the network jobs located near bus route networks in downtown of Kalamazoo and Portage and some other townships as shown in the figure.

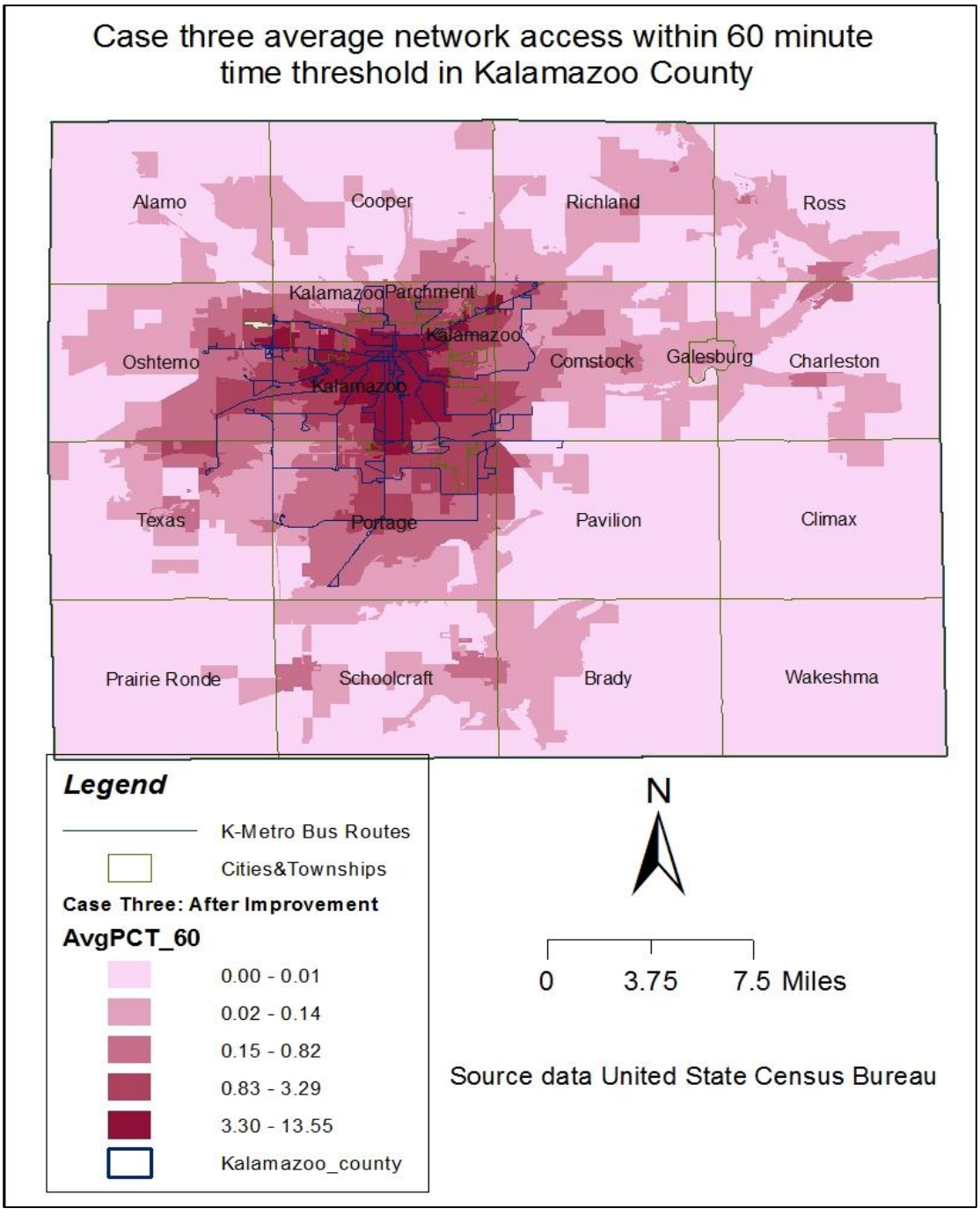


Figure 6-5 Average network access for 60-minute time threshold with wheelchair boarding consideration after improvement of prioritized bus stops in Kalamazoo county.

6.5 Comparison Between Accessibility Results of Case Three and Case Two

This section provides evidence that the improvement of prioritized inaccessible bus stops in Kalamazoo county has a significant impact in improving job accessibility efficiently for workers with physically reduced mobility, especially people who use a wheelchair. It denotes how the transit job accessibility measurement increases, while only 56.31% of the inaccessible bus stops improved for wheelchair boarding. The comparisons were conducted for all result sections, after running OTP. Some differences are represented by the bar chart over all Kalamazoo county such as, average number of boarding and job opportunity can be reached through public transit and walking in the study area. The other differences are represented in block level boundary such as average accessibility to network access, travel time, and walking distances to show how accurately these bus stops were selected for improvement to solve the reduction problem between Case One and Case Two. Due to the low cost for improvement, the prioritized process was economical, which has a significant role in developing business, job opportunity, and freedom or independence for disabled people. The percentage of differences for travel time and walking distance between Case Two and Case Three are shown in Appendix F.

6.5.1 Difference in Total Number of Jobs

The difference between total number of job opportunities which can be reached by workers through public transit or walking was measured for both cases in

AM peak period time between 7 and 10 at five-minute time steps. In Case Two, 70% of bus stops were not accessible but wheelchair boarding was considered while in Case Three, for solving the reduction problem 56.31% of inaccessible bus stops were selected for improvement and considered as accessible, and wheelchair boarding was considered as well. Analysis was carried out for four time thresholds such as 30, 60, 90 and 120 minutes. In the result, the difference in the number of jobs reached is shown for four time thresholds by the bar chart diagram in Figure 6-6 It is clear that the number of job opportunities reachable raised dramatically from 5122, 22659, 44530, and 61683 to 5633, 27522, 52057, and 66332 respectively for 30, 60, 90, and 120-time limit compared to original.

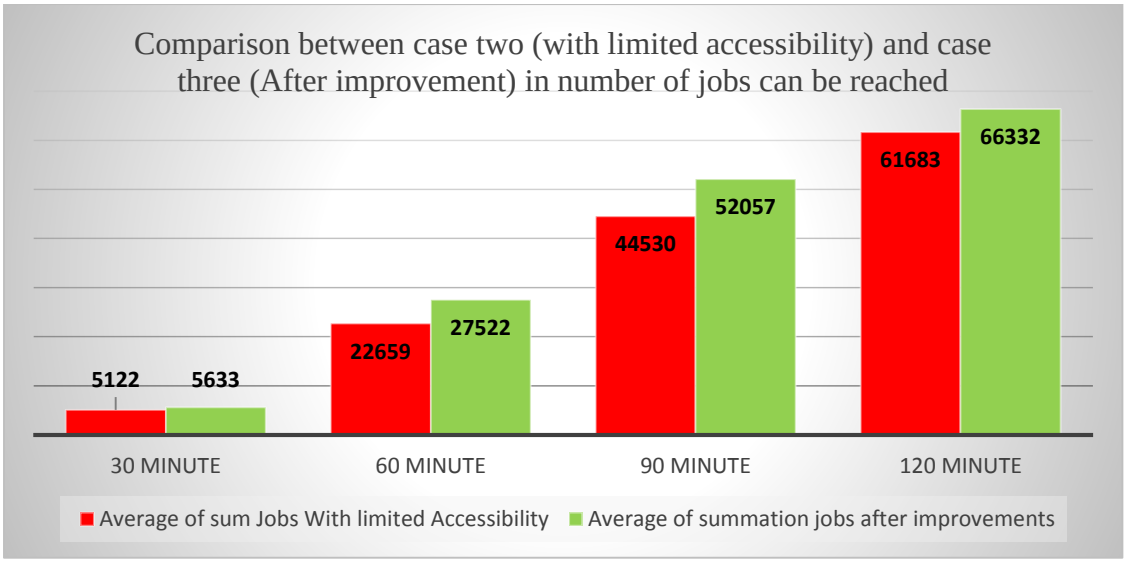


Figure 6-6 Comparison between Case Three and Case Two in number of jobs reachable.

In 60-minute or one-hour time threshold, which is more common for one time of transfer between buses and travel time in Kalamazoo county shows the highest percentage of increments, which is about 17.67% of number of jobs more accessible for people with reduced physical mobility which influences their freedom or independence in their lives.

6.5.2 Difference in Average of Network Access (Job Accessibility)

The difference in average of summation network access for workers who have access to the job network are represented in block level boundary by thematic map quantile option through ArcGIS software package. The difference in accessibility was calculated between Case Two and Case Three after improving selected bus stops and modifying GTFS data. In both cases, wheelchair boarding is considered. In Case Three, accessibility to network access increased significantly due to efficiently selected bus stops for improvement. This increment denoted by block level boundary compared to Case Two, while 70% of bus stops were not accessible, which has limited accessibility. The highest color density per category, which has an equal number of blocks inside, represents the highest increment in access to the job network as compared to Case Two. In four time thresholds, the highest increment happened in the corner of Cooper, Richland, and Comstock townships with Kalamazoo on one side. On the other side, the highest increment occurred in the corner of Oshtemo, Texas, and Portage township, with Kalamazoo. Also, some dense changes were seen

between Portage and Pavilion. Since time limit increases, the dense block categories increase such as, Figure 6-7, Figure 6-8, Figure 6-9, and Figure 6-10. Overall in Kalamazoo county, the percentage of increments in summation of network access due to 56.31% improvement of inaccessibility bus stops are 9.21% in 30 minute, 18.6% in 60 minute, 21.44% in 90 minute, and 21.67% in 120-minute time thresholds compared to Case Two.

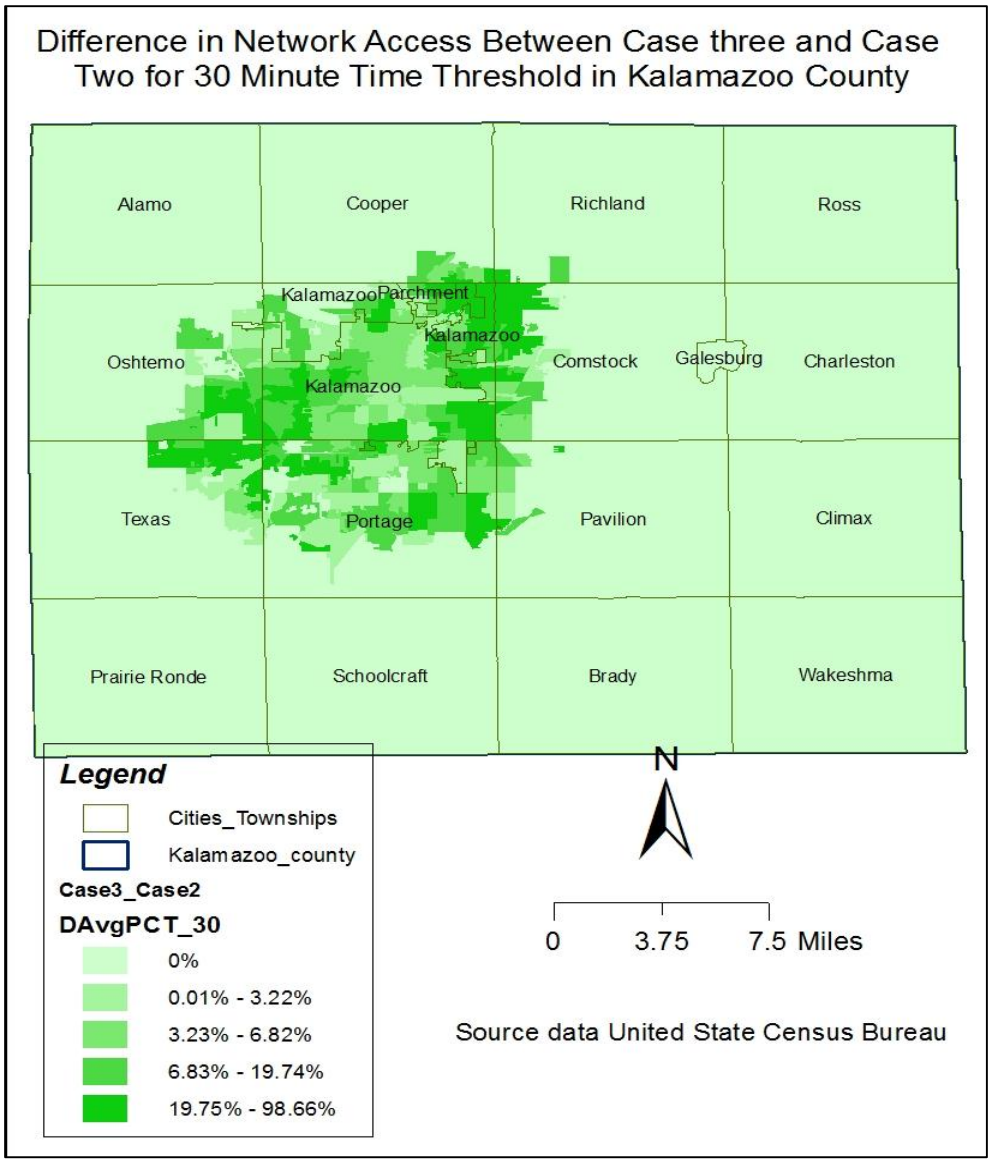


Figure 6-7 Difference in average network access for both Case Three and Case Two within 30-minute time limit in Kalamazoo county.

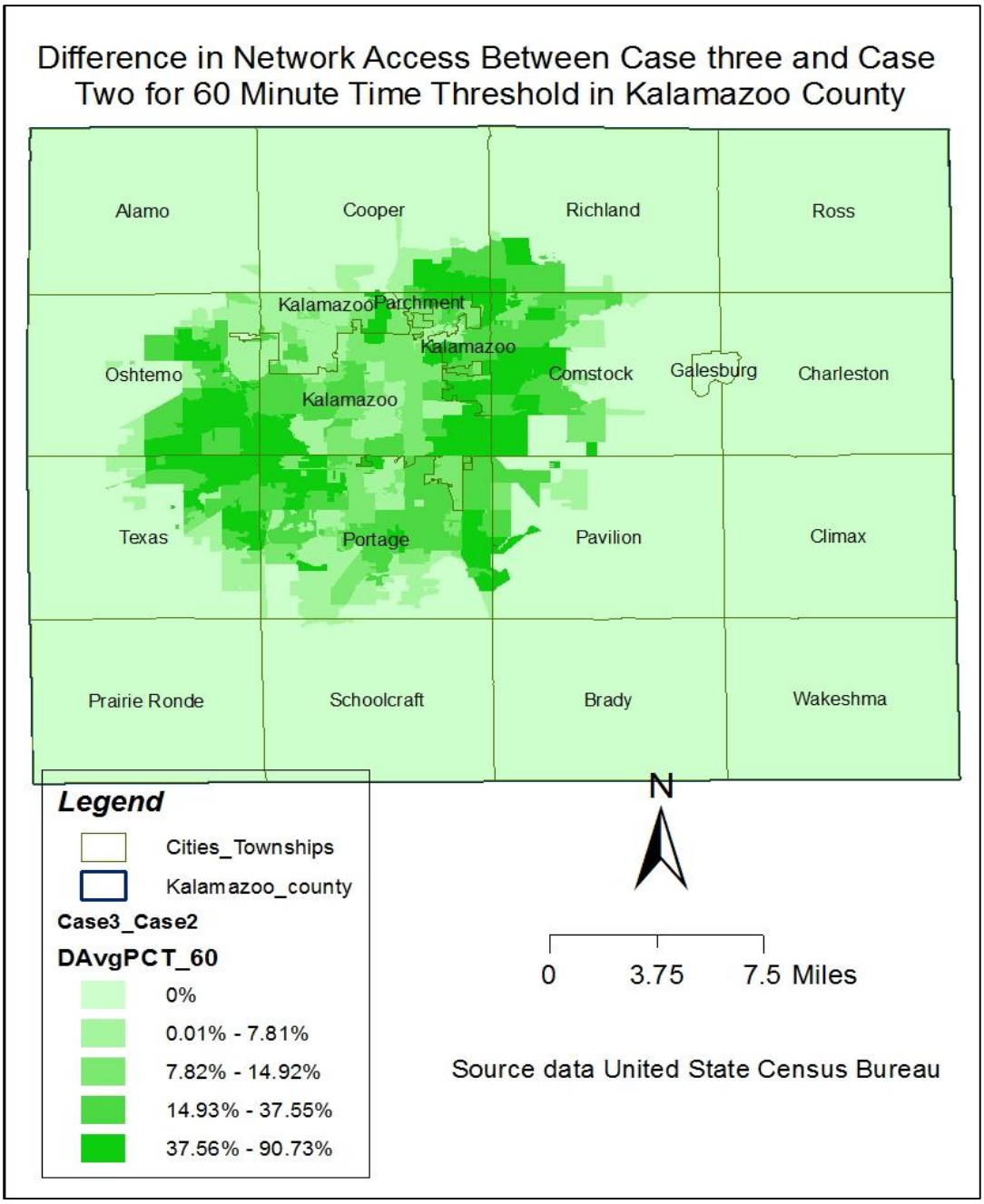


Figure 6-8 Difference in average network access for both Case Three and Case Two within 60-minute time limit in Kalamazoo county.

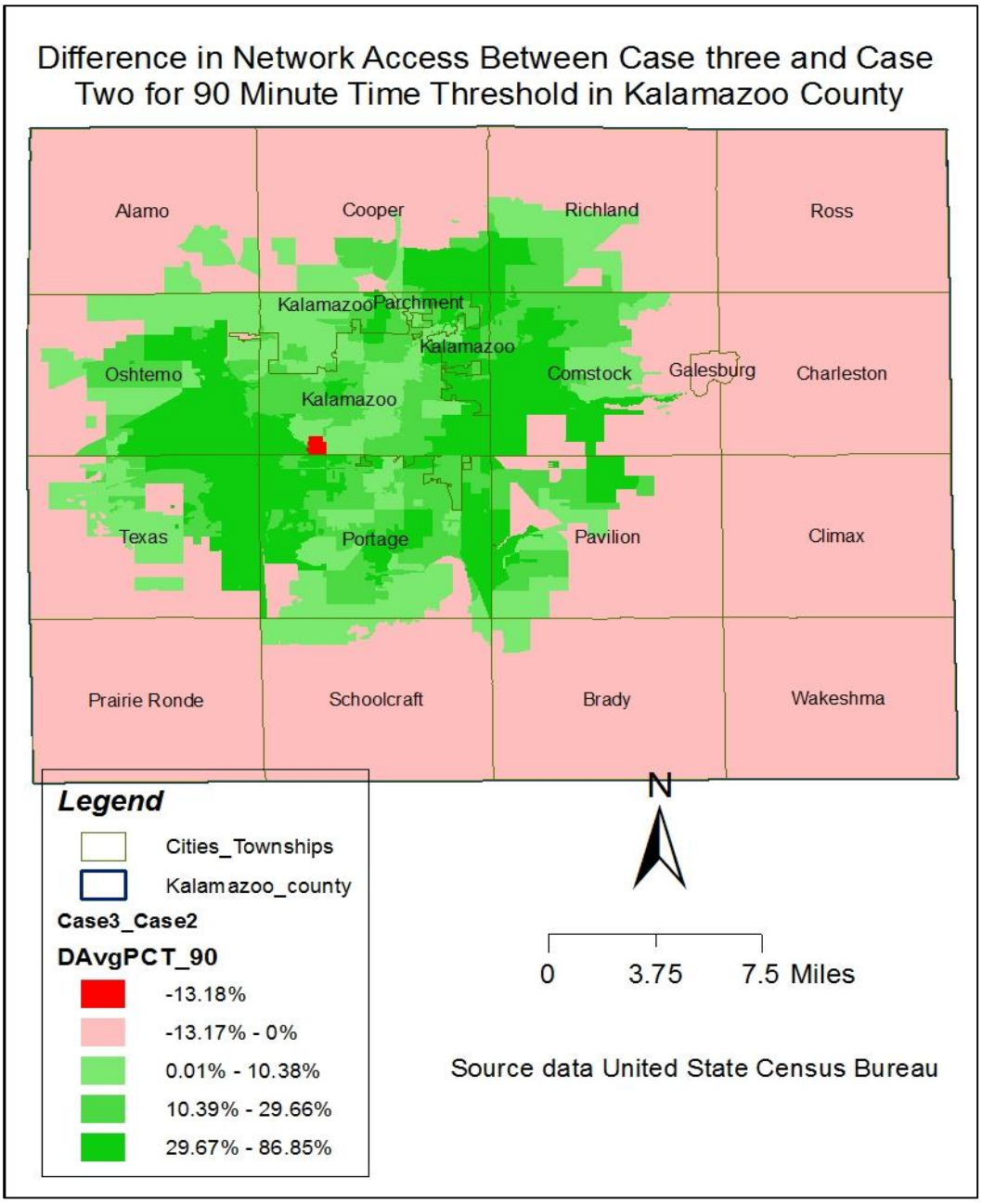


Figure 6-9 Difference in average network access for both Case Three and Case Two within 90-minute time limit in Kalamazoo county.

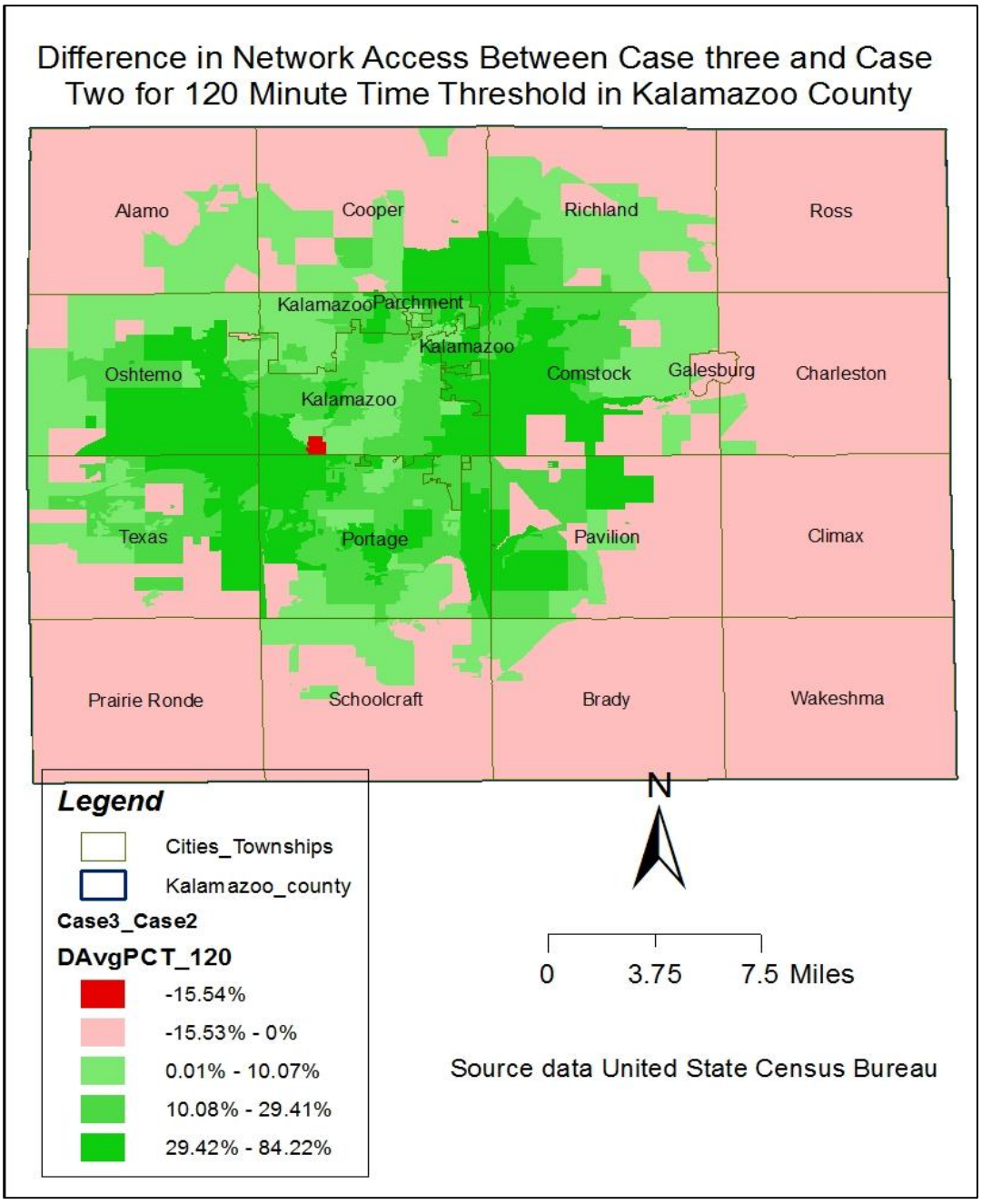


Figure 6-10 Difference in average network access for both Case Three and Case Two within 120-minute time limit in Kalamazoo county.

6.5.3 Difference in Total Number of Boarding

The number of boarding increased in Case Three due to 56.31% improvement of inaccessible bus stops. As clarified before, due to the DLZ survey, about 70% of bus stops were inaccessible in Kalamazoo county, which has a huge impact on accessibility measurement and number of boarding in the study area. In Case Three due to wisely selecting these bus stops for improvement, number of boarding increased, which approached close to a fully accessible model as Case One, while this number was much lower in Case Two due to limited accessibility of bus stops. The increments are summarized by a bar chart diagram in Figure 6-11.

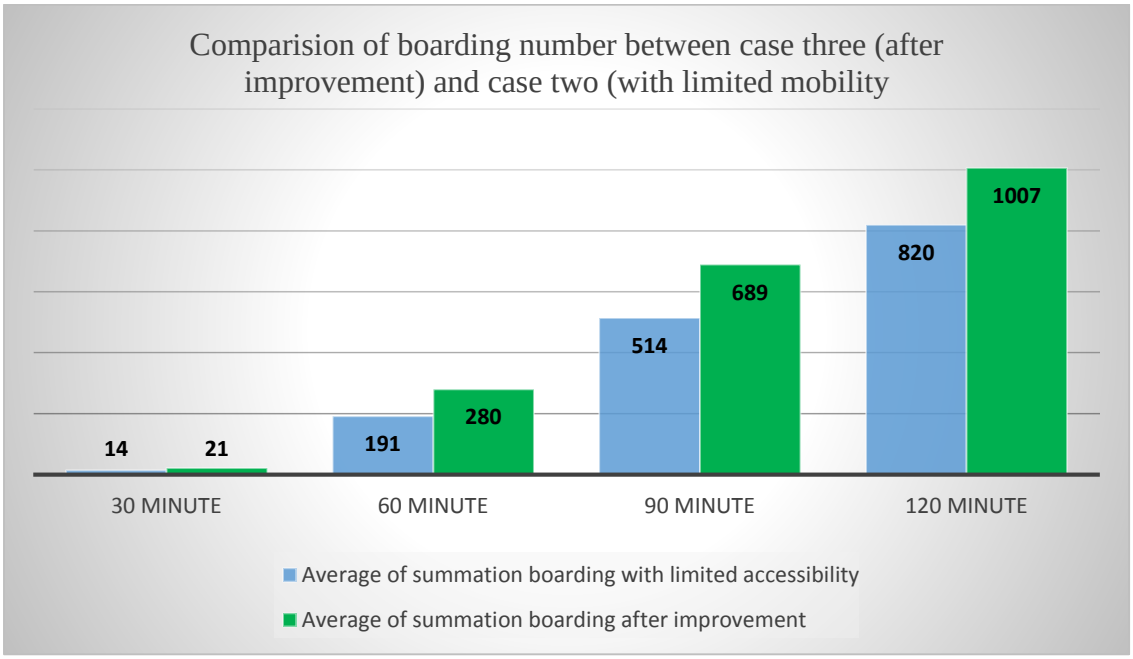


Figure 6-11 Difference between total number of boarding in Case Three and Case Two.

It is clear that the number of boarding increased in Case Three as compared to Case Two. The percentage of increment compared to Case Two is 33.33% in 30 minute, 31.8% in 60 minute, 25.4% in 90 minute, and 18.57% in 120-minute time thresholds, so the influence is big enough to solve a huge part of the reduction problems.

7 Conclusion

7.1 Summary

This study has put forward new techniques such as OTP and GTFS tools used with other public datasets to measure walking and transit accessibility to job destinations. OpenTripPlanner (OTP) implements Dijkstra's algorithm by using the shortest tree path method to calculate a series of origin-destination matrices with multi-modal travel times and distances. The measurements and results of this research in all three cases are important because it was carried out in a lower scale block boundary analysis, which offers chances for residents in various neighborhoods to figure out transit's influence on their living area. Moreover, transportation engineers and planners can assess the job access via transit for specific block or neighborhood area to make investments, build an economic expansion, and labor policy suggestions. Furthermore, it explores disparities in accessibility variation among people with reduced physical mobility such as people who use a wheelchair and who do not. In addition, this study presents an economical solution for the percentage of reduction in accessibility measurements while wheelchair boarding is considered in inaccessible bus stops in Kalamazoo county such as in Case Two. Prioritizing the selected bus stops has substantial benefits, because the highest number of disabled workers will gain an advantage for their trips from residence area to job location and vice versa. In spite of that, a significant increment in accessibility happened after improvement of

obstacles in bus stops for people with disabilities had been faced with. Numerous factors and discussions related to the accessibility are discussed in this chapter.

First of all, this research clearly explained that access to job destinations via public transit and walking are characterized by growing time threshold variabilities such as 30, 60, 90, and 120-minute at five-minute interval time steps. Likewise, growth of these time thresholds relies on how far destination from origin is, the availability of transit, and the frequency or headways along transit routes. This research shows a more complete picture of the degree to which individual workers who use a wheelchair or not to get to their jobs through public transit and to what degree jobs become accessible for them. Therefore, it is a more valid and effective measure of accessibility. Secondly, regarding the specific case study findings, the departure time at 5-minute interval continuous from 7 to 10 AM accessibility measures classify temporal, spatial, and demographic movements in accessing jobs via transit and distinguishes among transit travel times components. The analysis was carried out for three cases. In the first case, wheelchair boarding was not considered for original data. In the second case, limitation mobility was considered for workers who use a wheelchair by improving GTFS data and adding a wheelchair boarding column that was defined by (0 for no information about bus stops, 1 for accessible bus stops, and 2 for not accessible bus stops) based on the DLZ survey data (2014). Inaccessibility of bus stops tied with some influence and effective factors that make it difficult for people with a disability, such as connecting to pedestrian access route

PAR, availability of boarding platform, and compliance. In Kalamazoo county, about 70% of the bus stops are not accessible. In the third case, about half (56.31%) of inaccessible bus stops were selected for improvement and modified in GTFS data again, to solve the problem faced by people in the second case. Prioritizing these bus stops was based on the dense area of disabled workers by place of residence as origin and dense area of job numbers location as destination. Methodologies were described earlier in Chapter Five. Comparison between Case One and Case Two clearly shows how accessibility decreases when wheelchair boarding is taken into account. Therefore, this problem encourages people with physically reduced mobility to rely heavily on a private auto to commute to jobs. After improvement of inaccessible bus stops by providing boarding platform and connecting them with sidewalk compliance with ADAAG or PROWAG requirements shows it would help numerous people to switch from private car to transit, such as people on wheelchair and mother or others with a baby in a stroller. The comparison between Case Three and Case Two clearly shows how this improvement dramatically raised accessibility.

7.2 Findings

Overall, the vital benefits of this improvement were shown in the solution of percentage of reduction for three sectors, such as number of job opportunities that can be reached, average of summation of job network access, and number of boarding. The difference in number of jobs that can be reached is shown in Figure 7-1. Also, the

percentage of total 113706 jobs can be reached via transit and walking for the four time thresholds are shown in Table 7-1. It is obvious how the number of job opportunities approached Case One after improving 56.31% of inaccessible bus stops in Case Three.

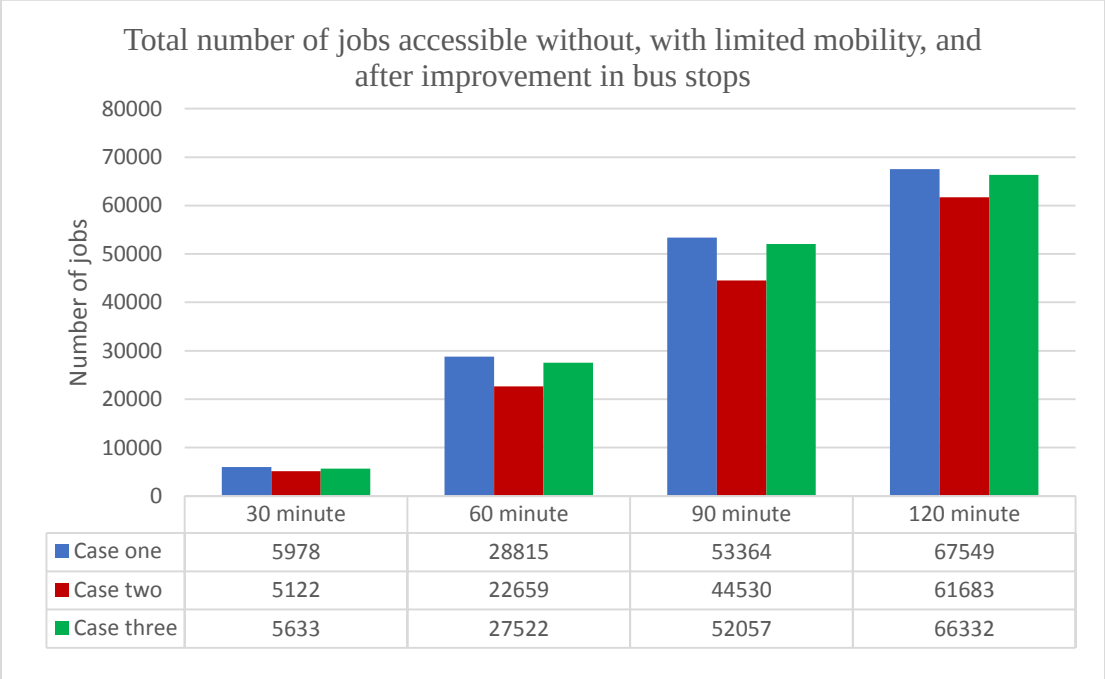


Figure 7-1 Total number of jobs can be reached via transit and walking in Case One, Case Two, and Case Three overall Kalamazoo county.

Table 7-1 Percentage of total 113706 jobs can be reached via transit and walking overall Kalamazoo county.

Time thresholds	Case one	Case two	Case three
30 minute	5.26%	4.50%	4.96%

Table 7-1 – continued

60 minute	**25.34%**	**19.92%**	**24.21%**
90 minute	46.93%	39.16%	45.78%
120 minute	59.41%	54.24%	58.34%

To clarify the percentage of solving the problem in each time thresholds after improving inaccessible bus stops in the above figure, Table 7-2 summarizes this ratio.

Table 7-2 Percentage of solution in reduction of total number of job opportunities overall Kalamazoo county.

First sector: Total number of jobs						
Time thresholds	Case one	Case two	Case three	Case two reduction.	Case three reduction	% Solution of the problem
30 minute	5978	5122	5633	14.32%	5.77%	59.71%
60 minute	28815	22659	27522	21.36%	4.48%	79.03%
90 minute	53364	44530	52057	16.56%	2.45%	85.20%
120 minute	67549	61683	66332	8.69%	1.81%	79.18%

According to the table, it is obviously clarified that 60% in 30-minute, 79% in 60-minute, 85% in 90-minute, and 79% in 120-minute of percentage of reduction were solved after improving about half the percentage of inaccessible bus stops.

In the second sector, the difference in average accessibility to the network access was described in Chapter Four and Five by block level for all three cases, but overall average accessibility for each case in Kalamazoo county is shown in Figure 7-2. The percentage of solutions of reduction problems is shown in Table 7-3.

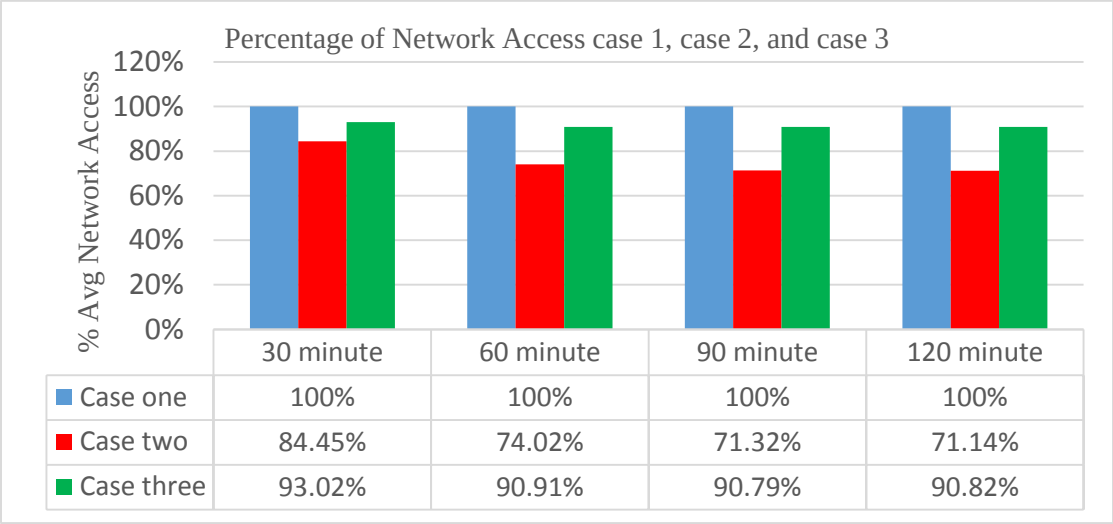


Figure 7-2 Percentage reduction of average network access via transit and walking in Case One, Case Two, and Case Three overall Kalamazoo county.

Table 7-3 Percentage of reduction and solution of average of network access overall Kalamazoo county.

Second Sector: Average of Network Access						
Time thresholds	Case one	Case two	Case three	Case two reduction.	Case three reduction	%Solution of the problem
30 minute	100%	84.45%	93.02%	15.55%	6.98%	55.11%

Table 7-3 - continued

60 minute	100%	74.02%	90.91%	25.98%	9.09%	65.01%
90 minute	100%	71.32%	90.79%	28.68%	9.21%	67.89%
120 minute	100%	71.14%	90.82%	28.86%	9.18%	68.19%

The above table shows that 55.11%, 65.01%, 67.89% and 68.19% of the reduction problem of getting access to the job network were solved for 30, 60, 90, and 120-minute time limit consequently after selecting 56.31% inaccessible bus stops for improvement. The 60 and 90-minute time thresholds most likely happen in Kalamazoo county due to one and two number of transfers among buses.

In the third sector, the difference in average of total number of boarding was described in Chapter Four between Case One and Case Two, after considering limited accessibility of bus stops to show how these numbers decrease. Also, the difference between Case Three and Case Two, after improvement of selected inaccessible bus stops switched to accessible showed how the number of boarding increased. Finally, both Case Two and Case Three are compared to Case One to show at what percentage the reduction problems were solved after improvement of selected prioritized bus stops. The average of summation boarding over all of Kalamazoo county for each case is shown in the Figure 7-3. The percentage of solution reduction problems after

improvement is shown in Table 7-4. It clearly shows that about 69.23% of the reduction was solved in 60-minute time limit and 77.35% of the reduction was solved 90-minute after improvement of the bus stops. Both 60 and 90 minute are more common to commute to job location in Kalamazoo county due to two number of transfers.



	30 minute	60 minute	90 minute	120 minute
Case one	28	320	740	1068
Case two	14	191	514	820
Case three	21	280	689	1007

Figure 7-3 Total number of boarding in Case One, Case Two, and Case Three overall Kalamazoo county.

Table 7-4 Percentage of reduction and solution of total number of boarding overall Kalamazoo county.

Third Sector: Total number of Boarding						
Time thresholds	Case one	Case two	Case three	Case two reduction.	Case three reduction	% Solution of the problem
30 minute	28	14	21	50.0%	25%	50.10%
60 minute	320	191	280	40.3%	12.5%	69.0%
90 minute	740	514	689	30.54%	6.9%	77.43%
120 minute	1068	820	1007	23.22%	5.71%	75.4%

To sum up, after improving about half the percentage of inaccessible bus stops, nearly three-quarters of the reduction problems were solved in the number of job opportunities seized, access to the job network, and number of boarding in bus stops. While retrofitting present infrastructure, the cost is habitually a significant factor, the challenge of building a new infrastructure accessible from the foundation does not come from incremental costs. Therefore, the decision for selecting bus stops for improvement should be made in a cost-effective manner, based on the potential improvement of accessibility for workers with disabilities. Due to the DLZ survey, the total estimate probable of retrofitting and construction cost to make inaccessible bus stops compliant is approximate $506,000. Therefore, the budget requirement would be decreased. A total estimated cost required only for origin bus stop stations

are $93,675 plus 30% of this cost for mobilization and general conditions cost. Origin bus stop stations are those bus stops which are located in those neighborhoods that have more people with disability, it can be counted as a departure bus stop points for disabled workers. Also, a total $83,078 plus 30% of this cost for mobilization and general conditions cost required for destination bus stops. Destination bus stops are those bus stops which are located in dense blocks of job in this research. The 58 bus stops which are common between both should be subtracted to not have duplication costs. Therefore, the total cost for improvement is $142,758 with 30% of mobilization, and general conditions cost is $42,827, so the final improvement cost estimate will be $185,585, which is less than half of the total cost for improving all selected bus stops. Finally, by this proficient selection, not just the accessibility values improved three-quarters, but also the cost of improvement decreased to one-third which is 36.67% of the total cost. Cost estimation per bus stop with bus ideas are shown in appendix A. The other benefits of this improvement can play a role on people with physically reduced mobility, such that they would get more independence and freedom to commute to job locations. Also, K-Metro transit would get more transit riders due to the increase in number of boarding, so more auto riders switch to transit. Therefore, it could solve part of the congestion traffic problems, there would be less fuel consumption, and a cleaner environment. Finally, due to the important role in modifying outcomes in the public service transports, overall Kalamazoo county residents get advantages by getting access to job locations more easily.

Therefore, it improves cost effectiveness and public benefits including business in the study area. Thus, these bus stops ought to be improved.

7.3 Limitations and Future Work

7.3.1 Limitations

Some of the limitations to this research can be defined as: First The GTFS data used is old GTFS data, with new coordinates from K-Metro, because the new GTFS data from K-Metro has more than 45 new bus stops which have no data in stop_times.txt file, therefore an error occurs during the OTP if schedule time is not available for these bus stops. Second, the measurement was carried out only from origin to destination, not vice versa, so two-way travel time was not considered. Third, in Case Two and Case Three origin data, the hypothesis was a presumed hypothesis that the workers as origin are disabled people who use a wheelchair, due to the unavailability of data by workers in wheelchairs for block level boundary and to make comparisons to show the value of the problem, but selecting inaccessible bus stops relies on real disabled worker by block group in 2013. Fourth, the travel time measurement for transit and walking job accessibility does not differentiate among range of age. Travel time for walking may vary, such as between the elderly and young people due to variation in walking speed. Fifth, all the input data for accessibility analysis and structural equation are from 2013 due to availability of data.

7.3.2 Future Work

In this methodology, there are numerous caveats concerning considerations for further research work. First, this measurement carried out for AM pick period time due to the bottle neck of commuting jobs at that time, so it is possible if measuring these for off pick period, especially during the time that people go back from destination to origin, and then the reverse measurement of two-way travel time could be counted. Also, there are a lot of part-time jobs or on second shift, which may not be available in the morning. Second, it would be interesting to have real data for people who use a wheelchair and commute to jobs via transit to make structural equations between accessibility and workers with a disability, and then compare to a structural equation for non-disabled people. Third, as mentioned, all the input data for accessibility analysis and structural equation were from 2013 data set due to availability of data. An interesting upcoming research would be to compare accessibility between 2016 and 2013 data to see how the improvements influence the transit job accessibility measurement in the study area. Another interesting follow-up study would be making a priority equation for selecting bus stops to see how accessibility changes in the network for changing one by one inaccessible bus stops consequently. Furthermore, measuring accessibility to a fire station or a public library would be another interesting idea as well.

7.4 Recommendations

First, structural GTFS data should be clearly defined as a wheelchair boarding column in the stop text file to match with field investigation about bus stops. For example, wheelchair boarding could be separated into three columns for each bus stop, such as connection to pedestrian access route PAR, availability of boarding platform, and compliance with ADAAG or PROWAG requirement. If wheelchair boarding only covers boarding platform, then another column should be added that is called connectivity to sidewalk or PAR, and both should be in compliance to better evaluate accessibility bus stops in GTFS data and match with the site engineer observation. If bus stops are not connected to the sidewalk, then how can people get access to it, especially people in wheelchairs. Second, for collecting data about disabled people, a special smart card or discount would help to identify where they use transit and at which bus stops to identify their locations.

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APPENDICES

A. Prioritized Inaccessible Bus Stops for Improvement with Cost Estimation

Table A-1 Prioritized inaccessible bus stops to be improved, which are located in residence-dense area of disabled workers (origin).

Stop id	Cost $	Stop id	Cost $	Stop id	Cost $	Stop id	Cost $	Stop id	Cost $	Stop id	Cost $
9	2120	185	196	309	780	386	280	471	140	677	896
20	2168	198	280	310	780	387	280	474	294	678	364
21	420	201	161	325	175	399	880	488	280	679	280
53	161	202	140	326	830	400	780	501	280	680	280
66	392	203	161	327	280	405	280	513	175	684	280
67	140	206	696	328	175	407	780	516	280	685	231
68	336	209	175	329	210	416	280	588	896	691	280
75	350	215	504	330	1590	417	780	589	406	704	175
80	280	225	2140	331	140	418	280	612	280	705	140
81	336	226	126	332	1140	419	780	613	280	794	280
82	2025	228	1262	342	210	420	140	614	280	799	280
83	2025	229	210	343	210	421	280	615	1480	1022	105
101	2710	230	280	345	140	422	140	616	315	1030	952
107	780	234	280	346	140	423	140	617	280	1031	350
108	280	235	780	352	175	431	280	620	140	1042	280
109	280	237	780	353	280	438	280	621	140	1043	780
110	280	238	280	355	280	439	210	624	245	1044	780
117	140	239	280	357	280	440	140	626	210	1047	3600
127	280	240	280	358	175	441	140	627	210	1048	784
128	280	242	315	359	175	442	140	629	1731	1049	315
130	280	243	140	361	140	443	392	630	1745	1051	780
131	280	247	780	362	231	444	280	631	392	1054	140
132	245	248	392	363	280	456	280	634	616	1056	140
134	140	302	886	367	210	457	280	635	280	1065	175
137	1990	303	210	368	210	458	280	638	245	1067	140
162	780	304	485	372	175	459	280	640	245	1068	420
163	780	305	686	382	140	460	140	662	105	1072	3465
164	1960	306	780	383	280	462	780	663	780	1076	3295
165	810	307	922	384	280	463	280	667	280	1078	175
166	1280	308	280	385	175	464	280	676	140	1080	280

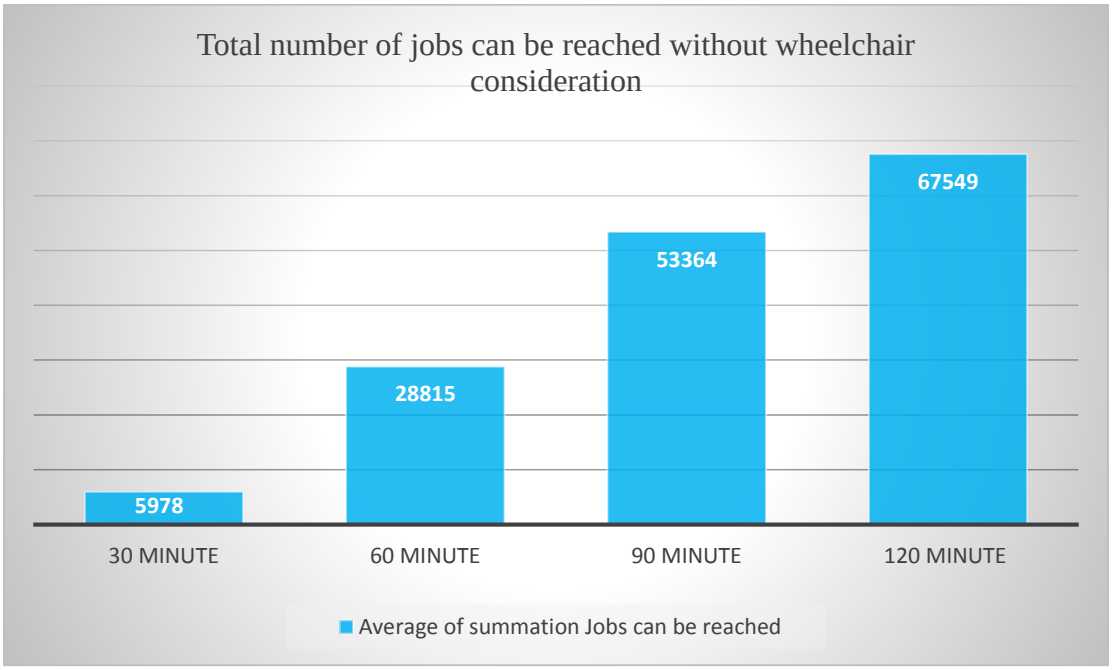
Table A-2 Prioritized inaccessible bus stops to be improved, which are located in dense area of jobs location (destination).

Stop id	Cost $	Stop id	Cost $	Stop id	Cost $	Stop id	Cost $	Stop id	Cost $	Stop id	Cost $
15	518	155	780	324	780	446	70	506	280	1029	780
18	280	156	780	325	175	447	450	513	175	1030	952
21	420	162	780	326	830	449	70	514	714	1037	280
23	105	163	780	327	280	454	70	516	280	1047	3600
35	210	164	1960	328	175	455	175	520	196	1048	784
53	161	165	810	329	210	456	280	521	161	1051	780
63	175	167	175	330	1590	457	280	546	780	1052	780
69	280	168	280	347	280	458	280	547	280	1053	280
74	280	173	196	352	175	459	280	560	140	1054	140
76	280	175	476	353	280	460	140	579	780	1056	140
77	280	179	196	355	280	462	780	580	280	1063	280
78	280	228	1262	359	175	463	280	585	364	1064	140
88	175	229	210	372	175	464	280	588	896	1065	175
95	105	276	780	377	1390	466	280	589	406	1071	280
98	2245	281	280	405	280	467	1148	593	780	1072	3465
101	2710	307	922	414	280	468	420	595	336	1073	280
102	350	308	280	415	280	472	140	625	210	1077	280
103	175	311	280	416	280	473	140	635	280		
104	210	312	280	417	780	477	280	661	780		
105	780	313	280	428	175	478	780	674	231		
107	780	314	780	432	1050	488	280	689	280		
108	280	315	780	434	780	491	140	690	780		
112	280	316	780	435	280	493	140	691	280		
116	2080	317	280	436	315	494	280	695	280		
127	280	318	280	437	2375	495	280	696	780		
132	245	319	780	439	210	496	1060	697	280		
142	280	320	280	440	140	501	280	704	175		
144	231	321	280	443	392	502	280	712	280		
147	780	322	280	444	280	503	336	713	280		
148	210	323	780	445	70	505	780	714	105		

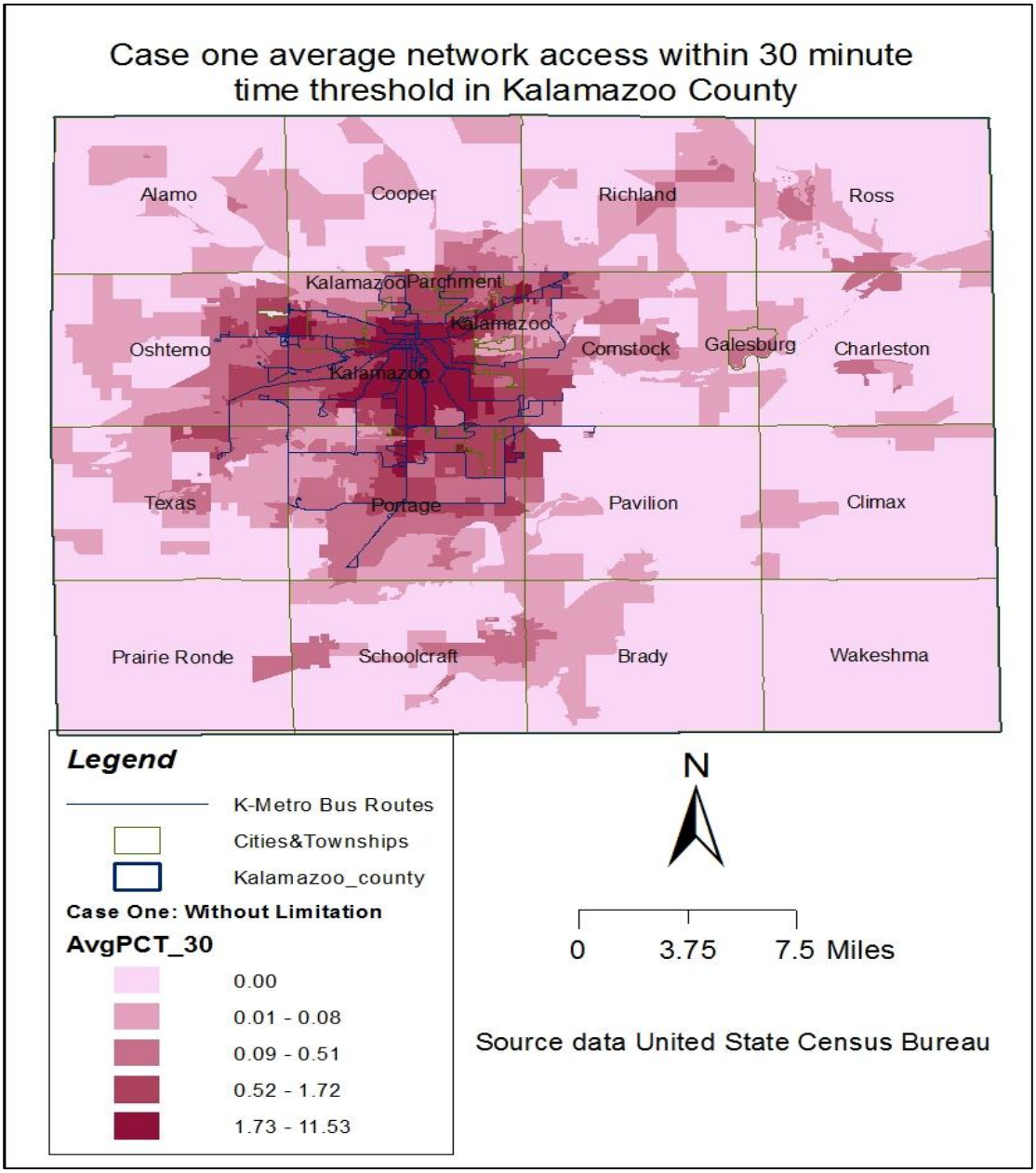
B. Case One Results: (Without Considering Limited Physical Mobility)

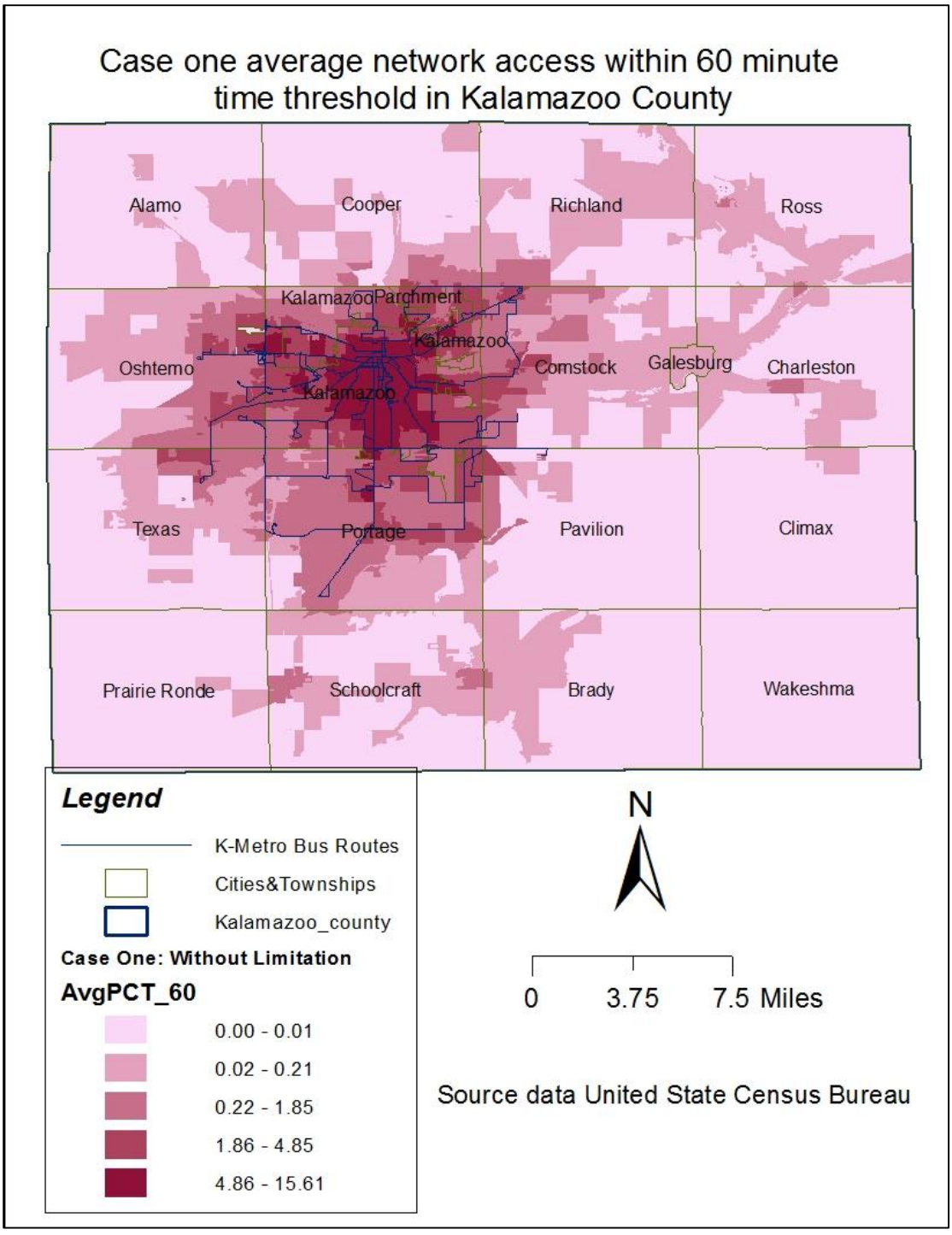
In original case, reduced physical mobility workers who use a wheelchair were not considered in measuring transit accessibility for jobs, the results were obtained after running OTP can be represented as the following sections.

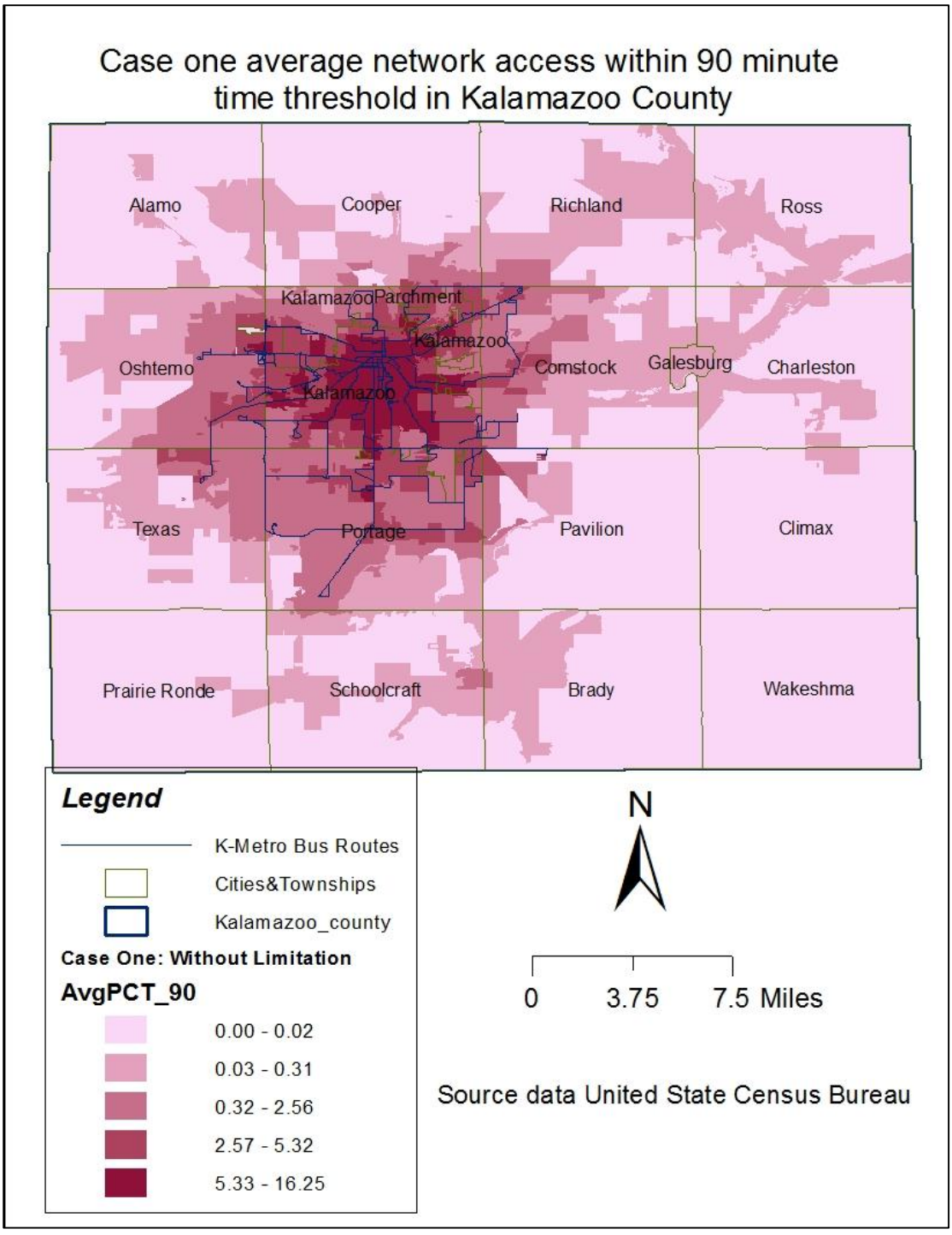
B-1. Total Number of Jobs

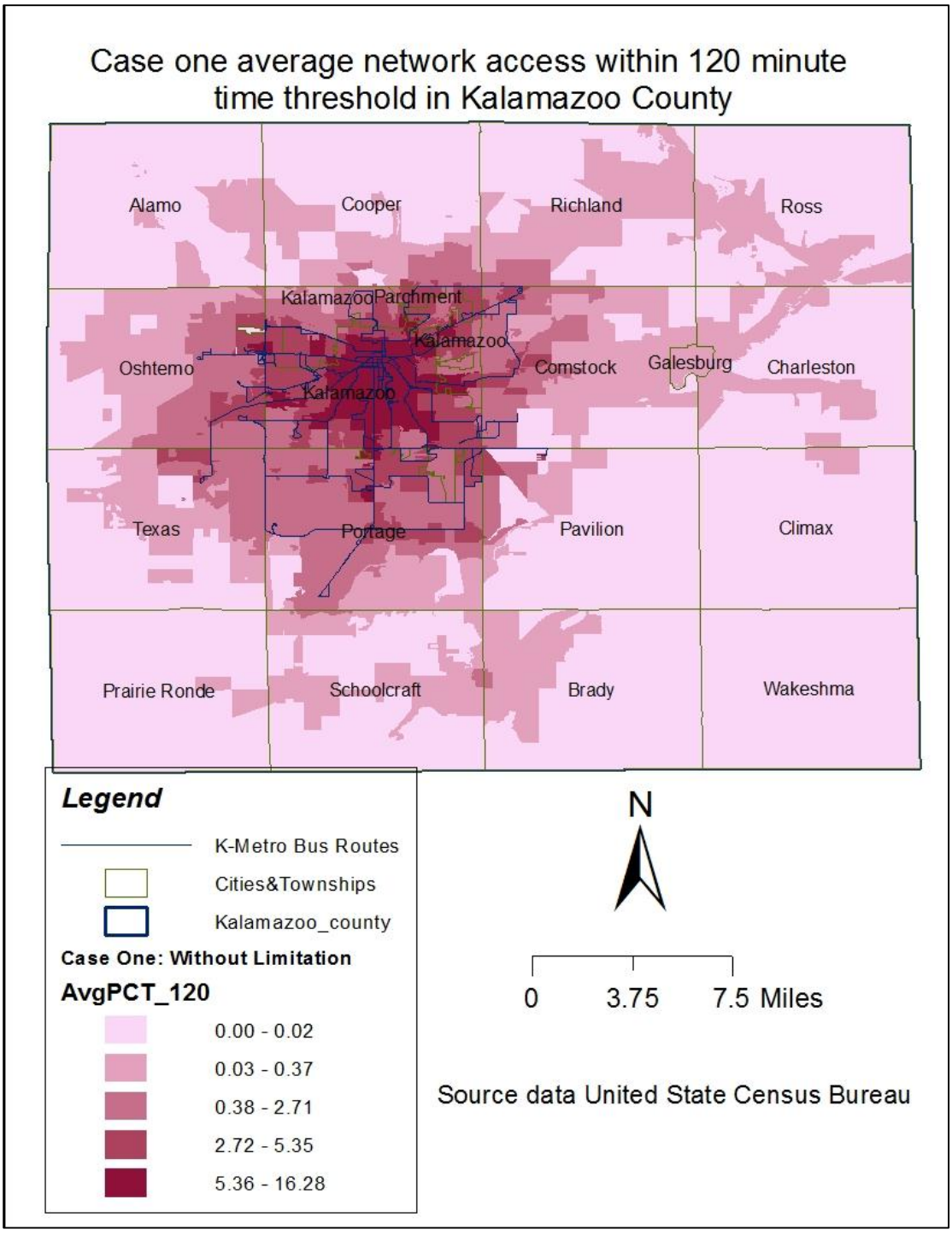


B-2. Average of Network Access (Job Accessibility)

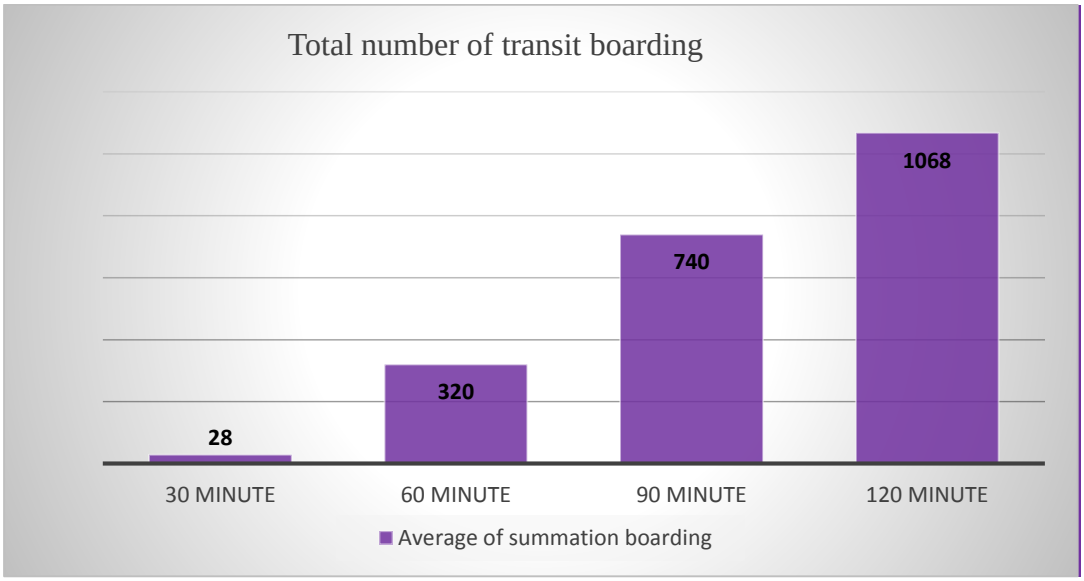



Case one average network access within 60 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Kalamazoo_county
Case One: Without Limitation
AvgPCT_60
0.00 - 0.01
0.02 - 0.21
0.22 - 1.85
1.86 - 4.85
4.86 - 15.61
N
0
3.75
7.5 Miles
Source data United State Census Bureau

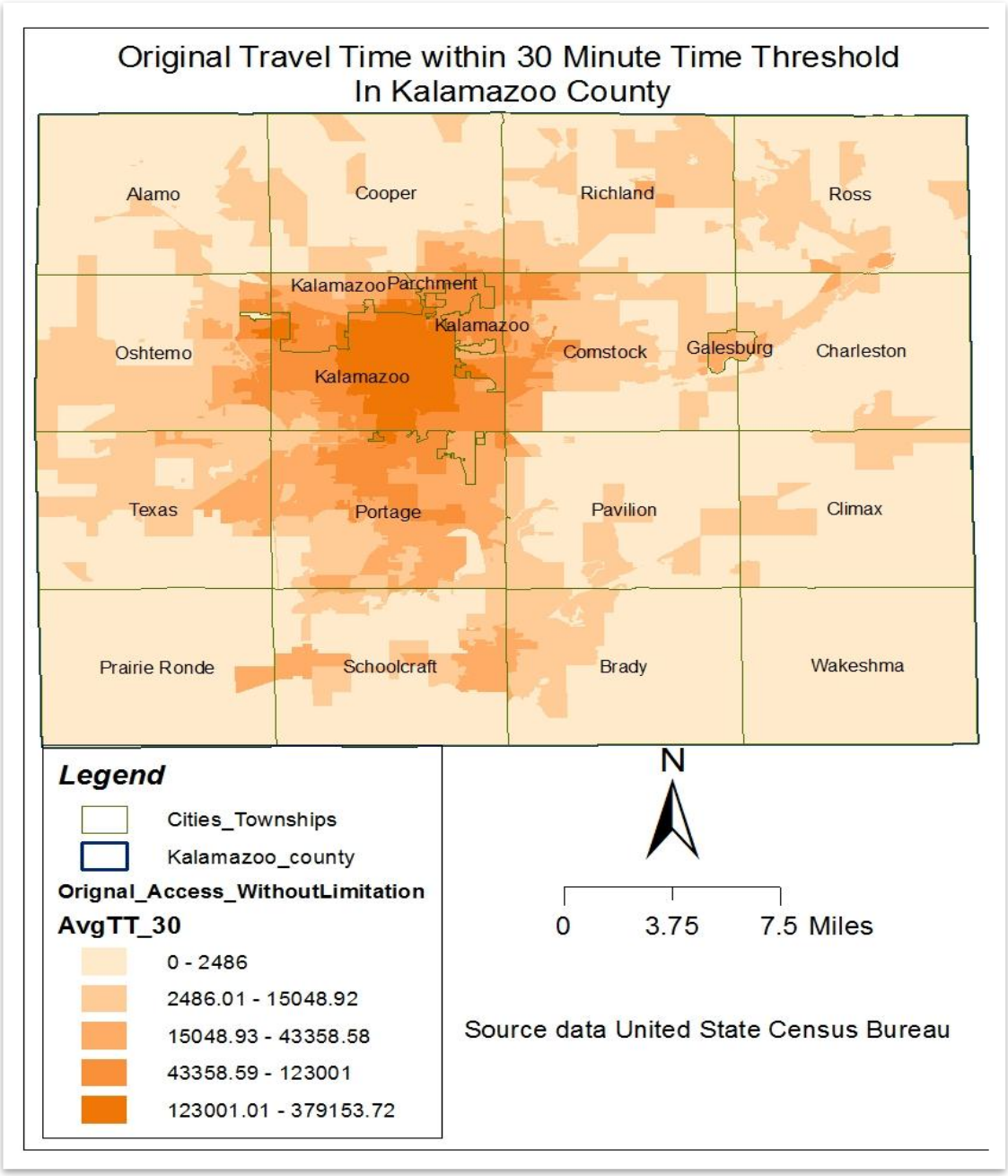

Case one average network access within 90 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Kalamazoo_county
Case One: Without Limitation
AvgPCT_90
0.00 - 0.02
0.03 - 0.31
0.32 - 2.56
2.57 - 5.32
5.33 - 16.25
N
0
3.75
7.5 Miles
Source data United State Census Bureau

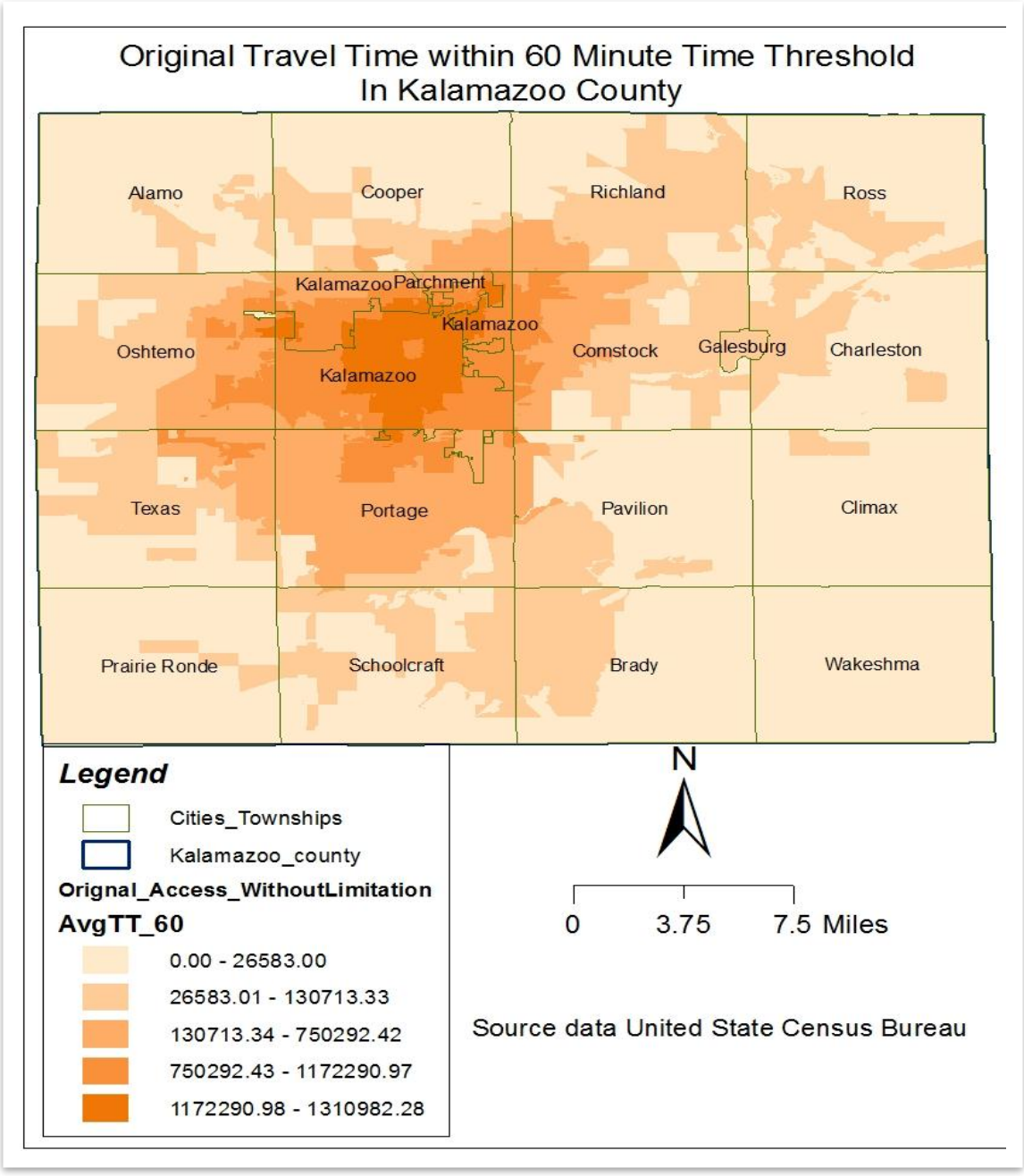

Case one average network access within 120 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Kalamazoo_county
Case One: Without Limitation
AvgPCT_120
0.00 - 0.02
0.03 - 0.37
0.38 - 2.71
2.72 - 5.35
5.36 - 16.28
N
0
3.75
7.5 Miles
Source data United State Census Bureau

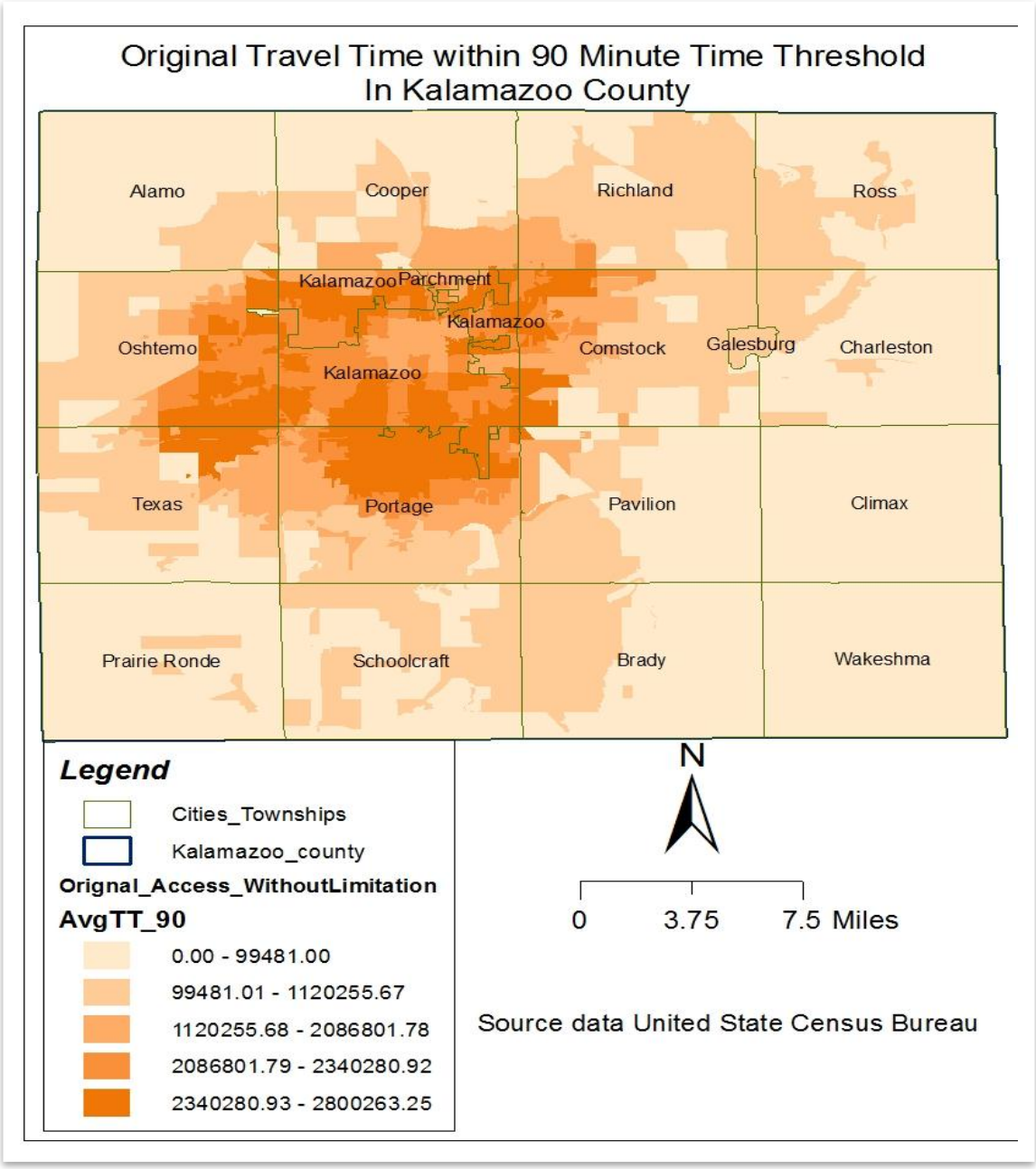
B-3. Total Number of Boarding

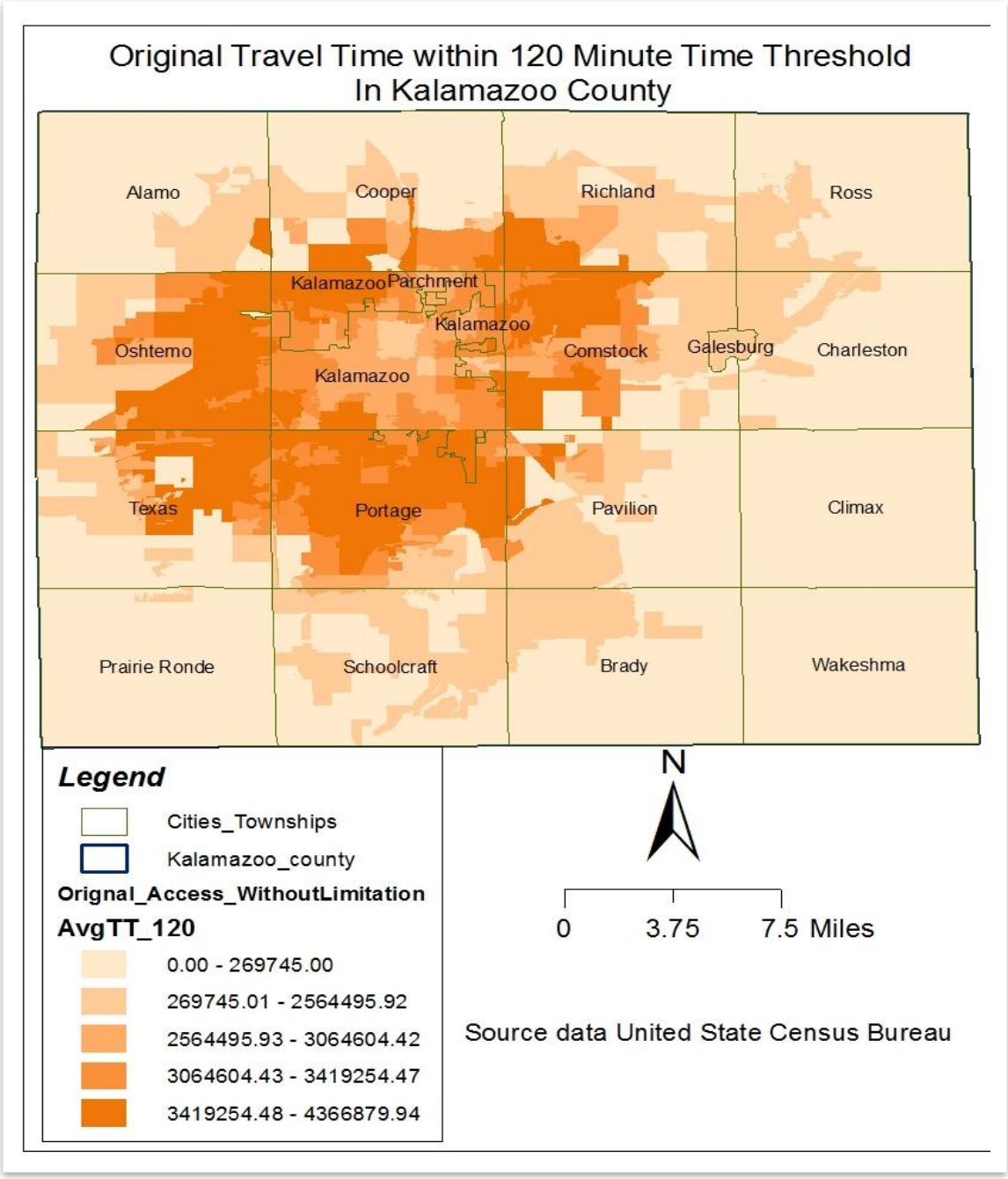


B-4. Average Travel Time

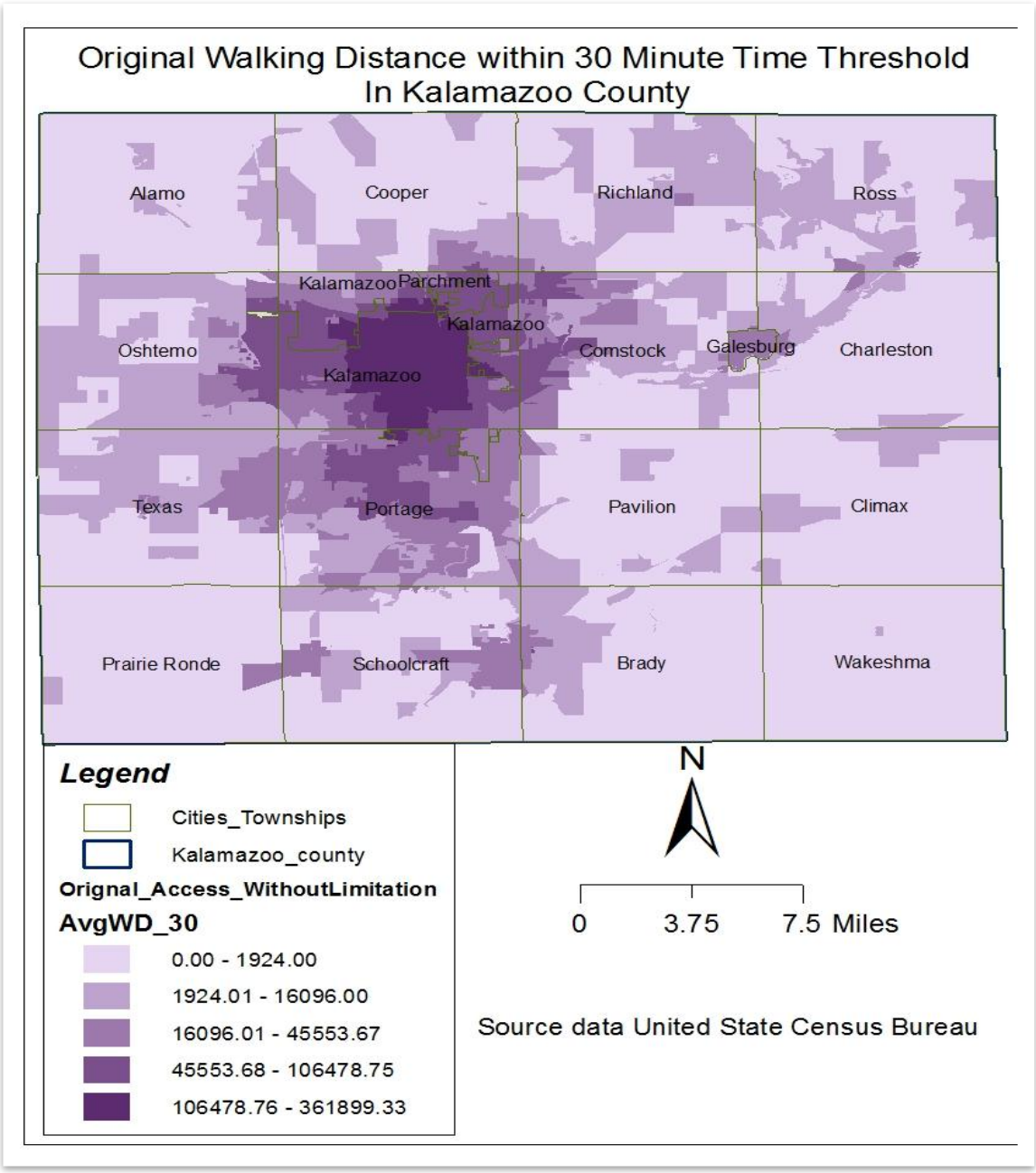


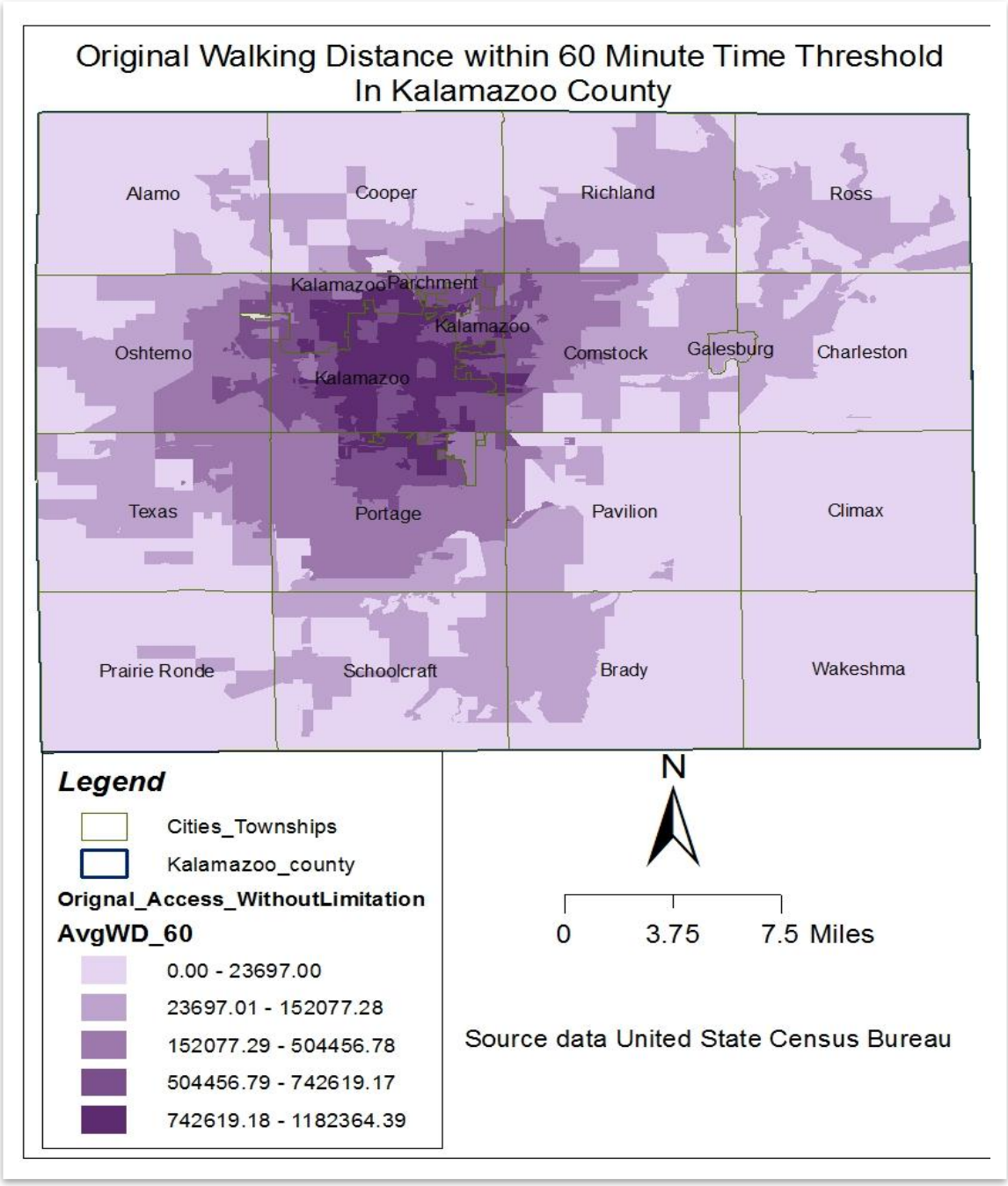

Original Travel Time within 60 Minute Time Threshold
In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Orignal_Access_WithoutLimitation
AvgTT_60
0.00 - 26583.00
26583.01 - 130713.33
130713.34 - 750292.42
750292.43 - 1172290.97
1172290.98 - 1310982.28
N
0
3.75
7.5 Miles
Source data United State Census Bureau

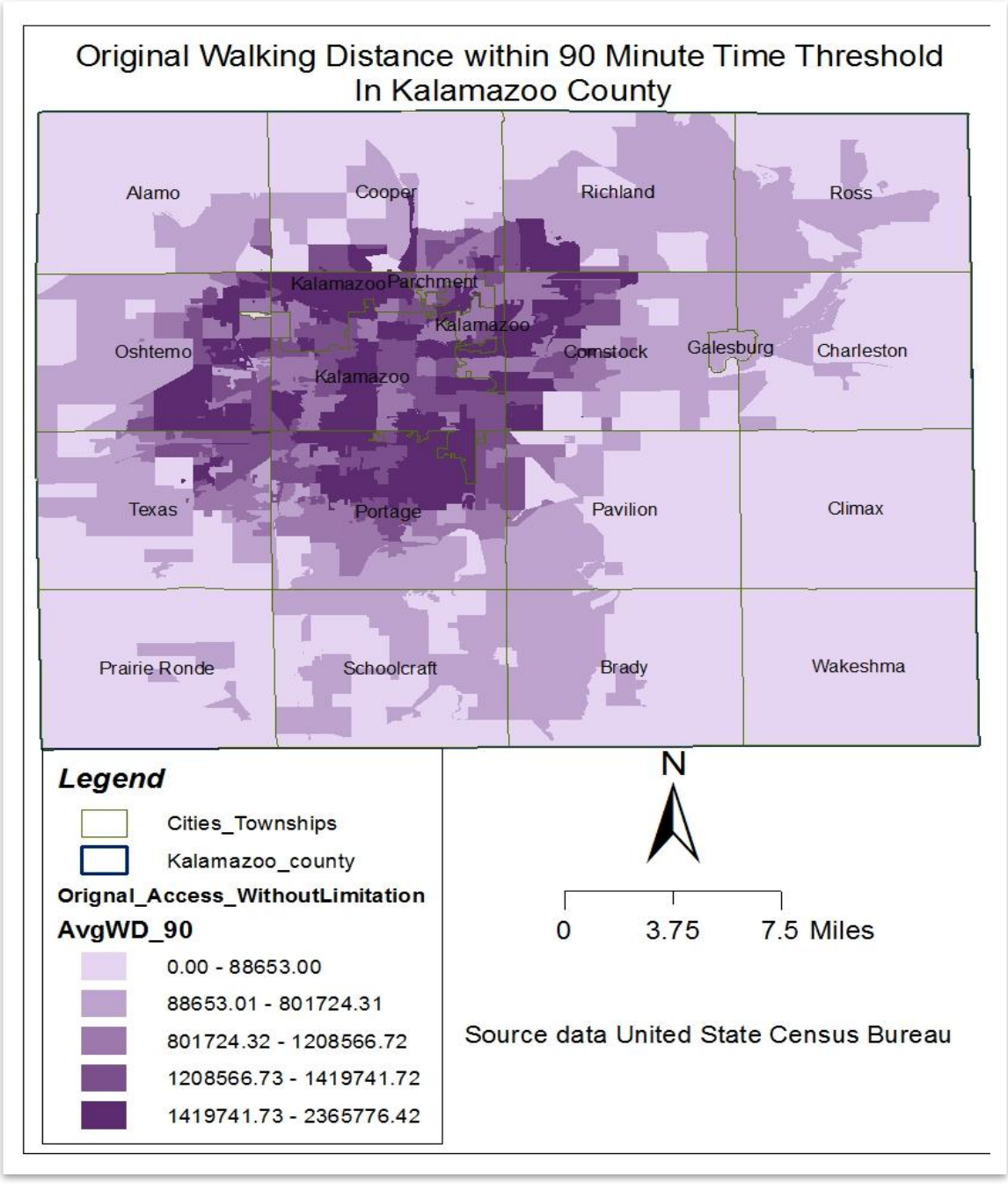

Original Travel Time within 90 Minute Time Threshold
In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Orignal_Access_WithoutLimitation
AvgTT_90
0.00 - 99481.00
99481.01 - 1120255.67
1120255.68 - 2086801.78
2086801.79 - 2340280.92
2340280.93 - 2800263.25
N
0
3.75
7.5 Miles
Source data United State Census Bureau

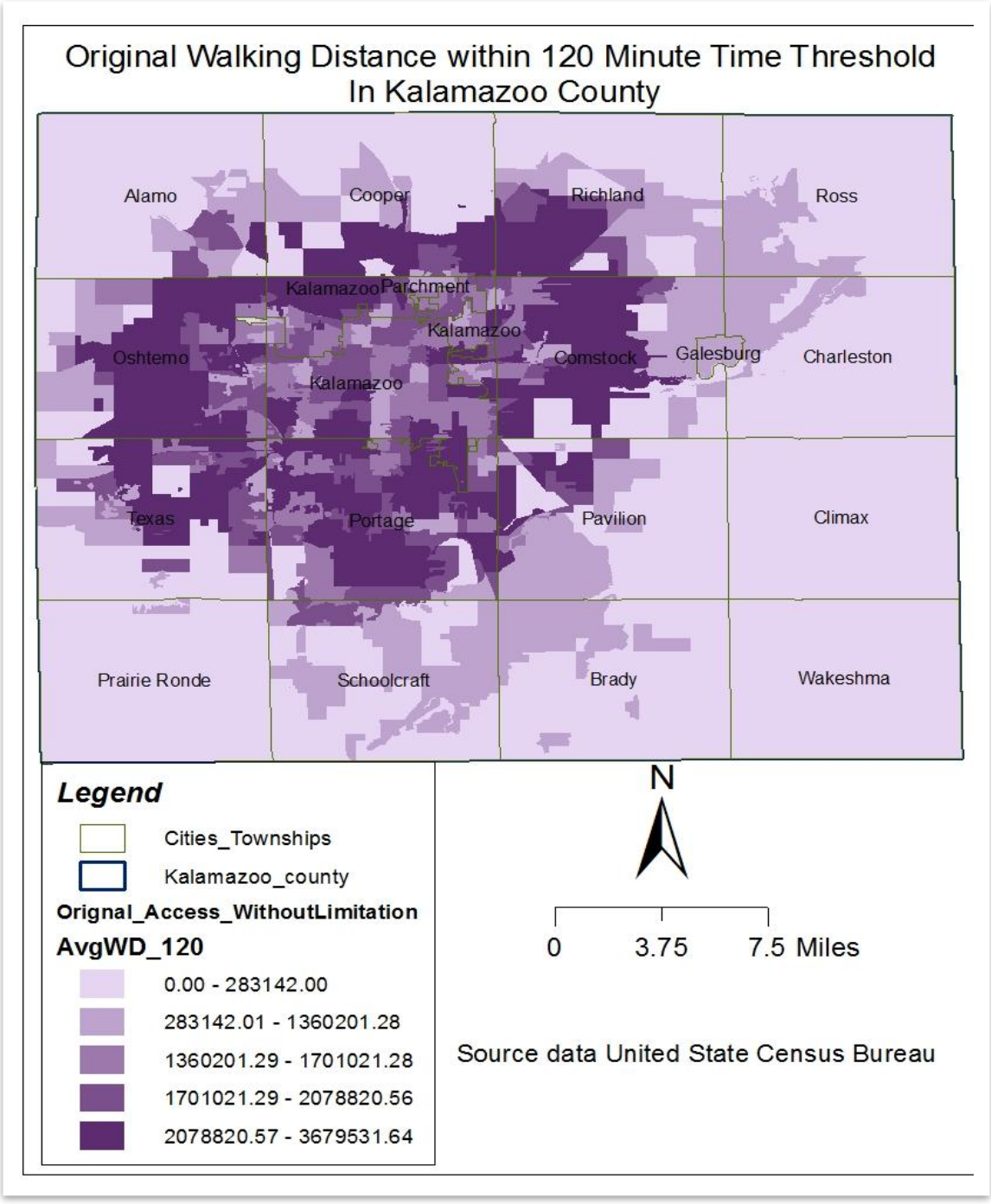

Original Travel Time within 120 Minute Time Threshold
In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Orignal_Access_WithoutLimitation
AvgTT_120
0.00 - 269745.00
269745.01 - 2564495.92
2564495.93 - 3064604.42
3064604.43 - 3419254.47
3419254.48 - 4366879.94
N
0
3.75
7.5 Miles
Source data United State Census Bureau

B-5. Average Walking Distance




Original Walking Distance within 60 Minute Time Threshold
In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Orignal_Access_WithoutLimitation
AvgWD_60
0.00 - 23697.00
23697.01 - 152077.28
152077.29 - 504456.78
504456.79 - 742619.17
742619.18 - 1182364.39
N
0
3.75
7.5 Miles
Source data United State Census Bureau

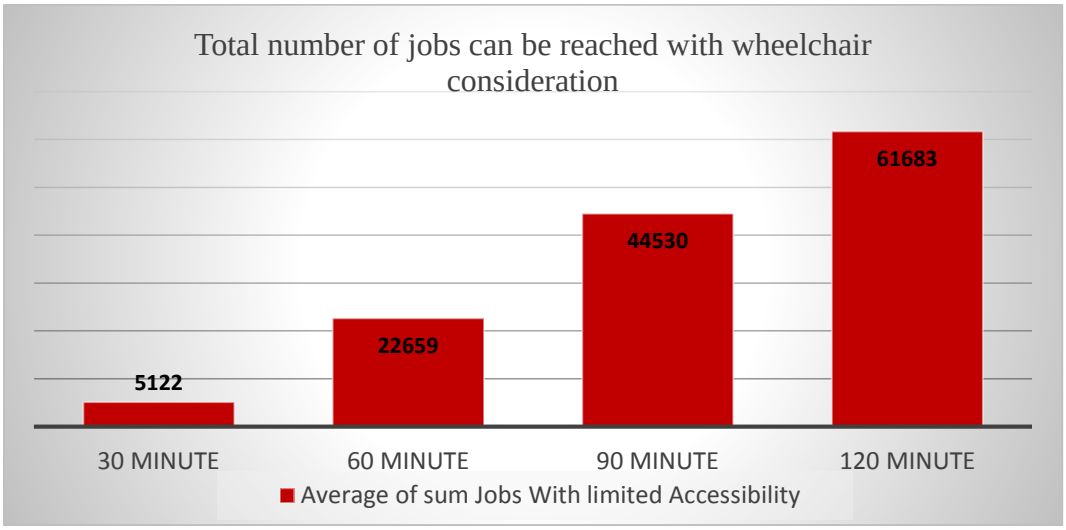

Original Walking Distance within 90 Minute Time Threshold
In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Orignal_Access_WithoutLimitation
AvgWD_90
0.00 - 88653.00
88653.01 - 801724.31
801724.32 - 1208566.72
1208566.73 - 1419741.72
1419741.73 - 2365776.42
N
0
3.75
7.5 Miles
Source data United State Census Bureau


Original Walking Distance within 120 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Orignal_Access_WithoutLimitation
AvgWD_120
0.00 - 283142.00
283142.01 - 1360201.28
1360201.29 - 1701021.28
1701021.29 - 2078820.56
2078820.57 - 3679531.64
N
0
3.75
7.5 Miles
Source data United State Census Bureau

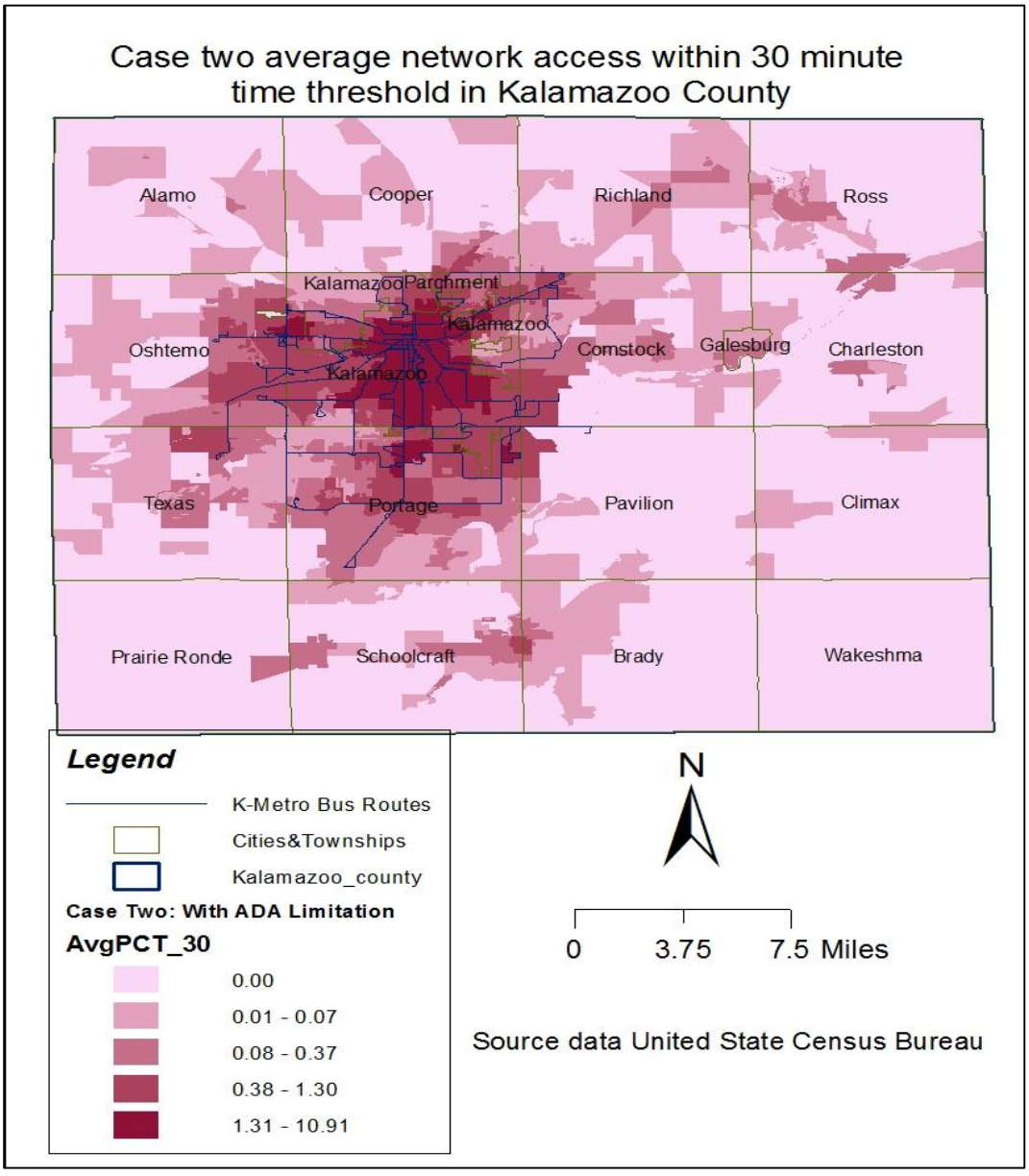
C. Case Two Results: (Considering Limited Physical Mobility)

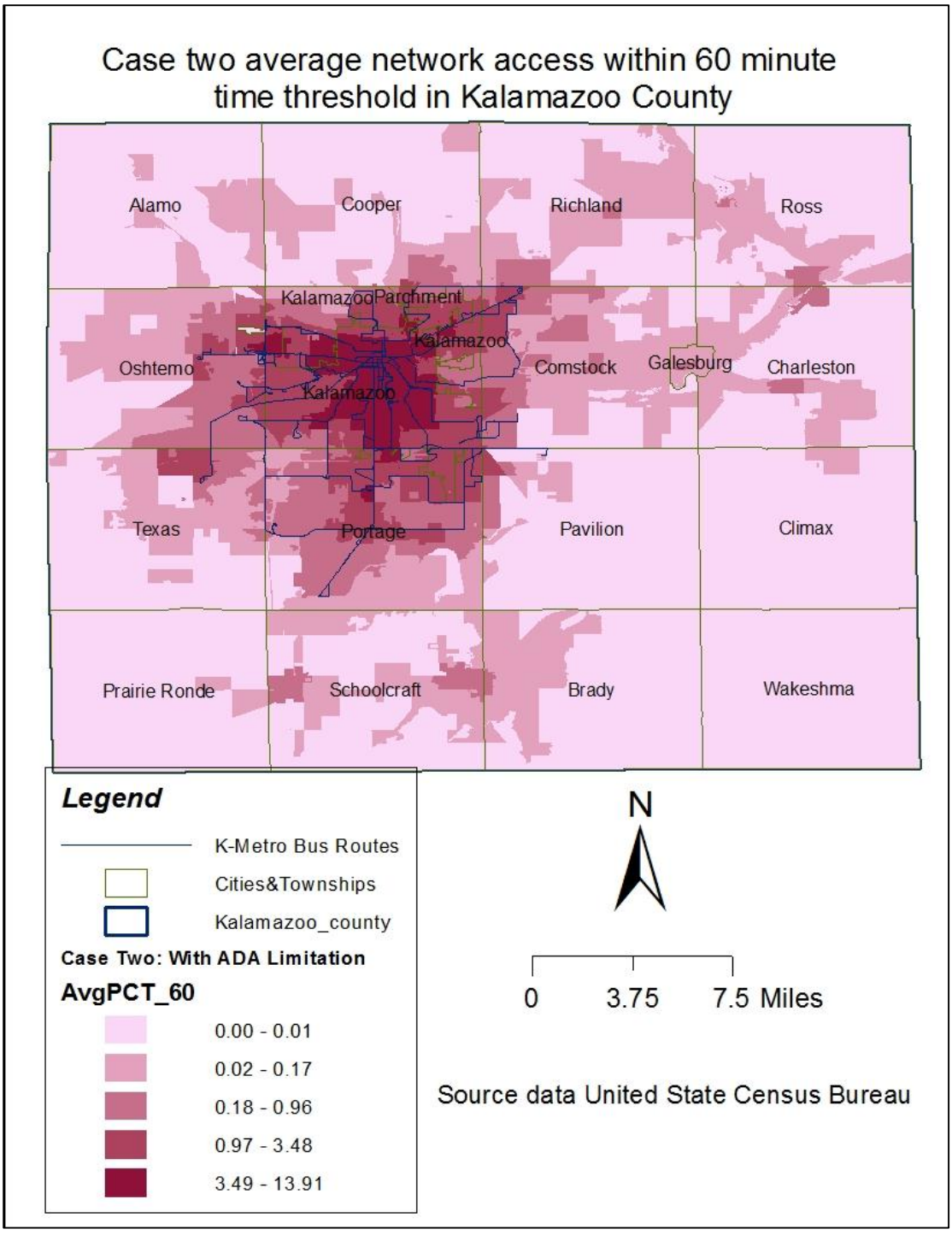
In second case, reduced physical mobility workers who use a wheelchair were taken into account in measuring transit accessibility for jobs due to the problems facing people who riding on wheelchair in Kalamazoo county in order to find a suitable solution for increasing transit job accessibility for them. The results were obtained after running OTP which can be shown as the following sections.

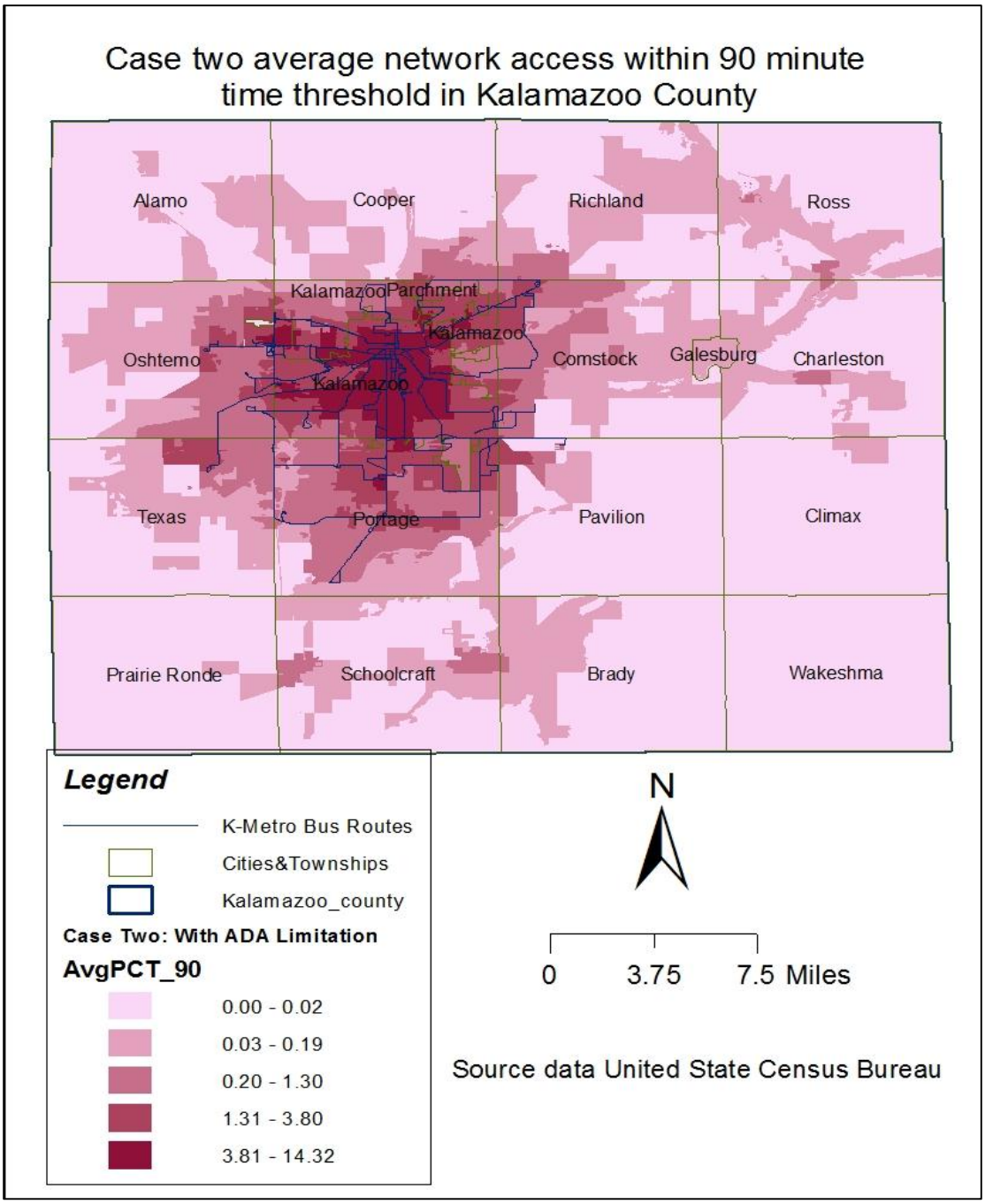
C-1. Total Number of Jobs

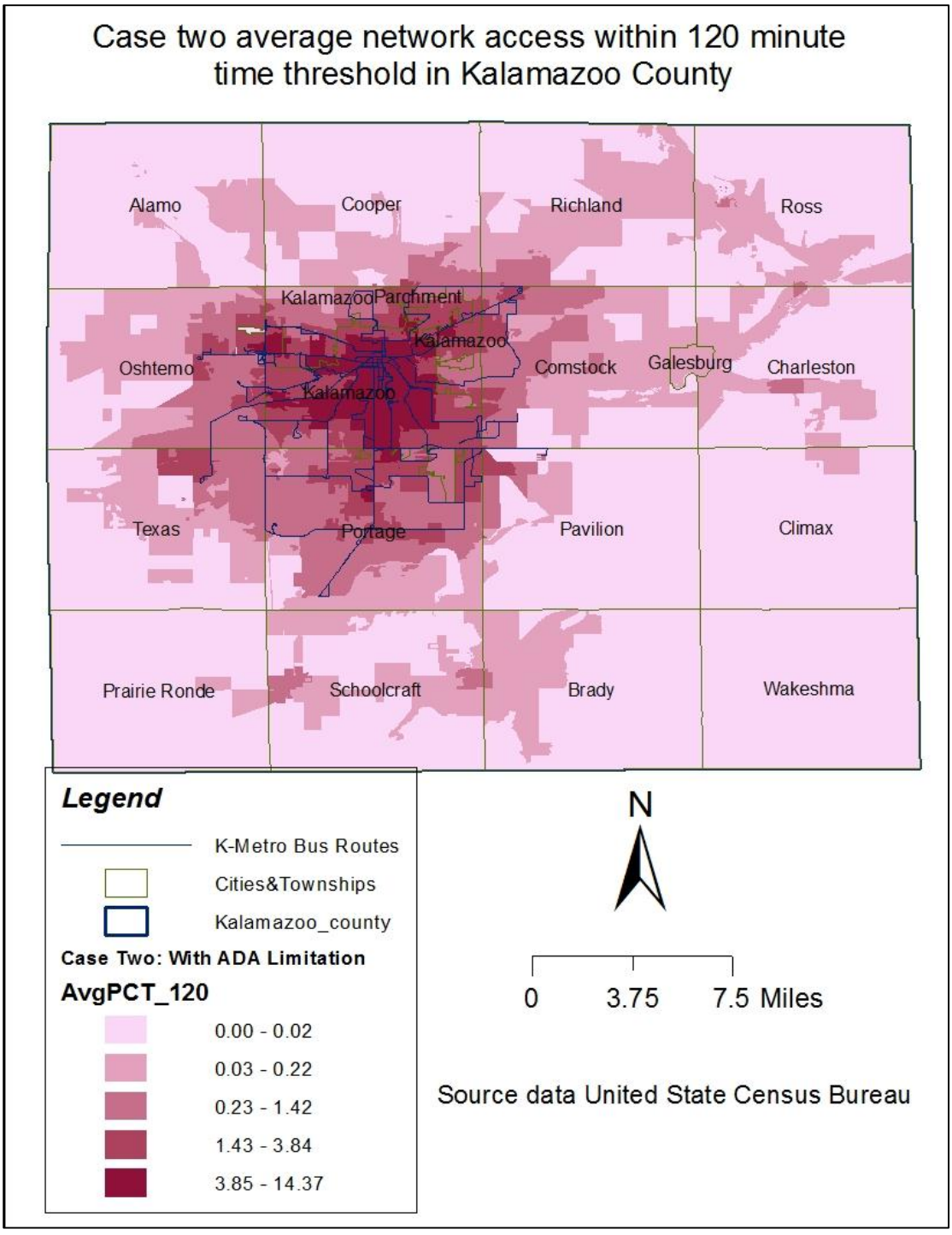


C-2. Average of Network Access (Job Accessibility)

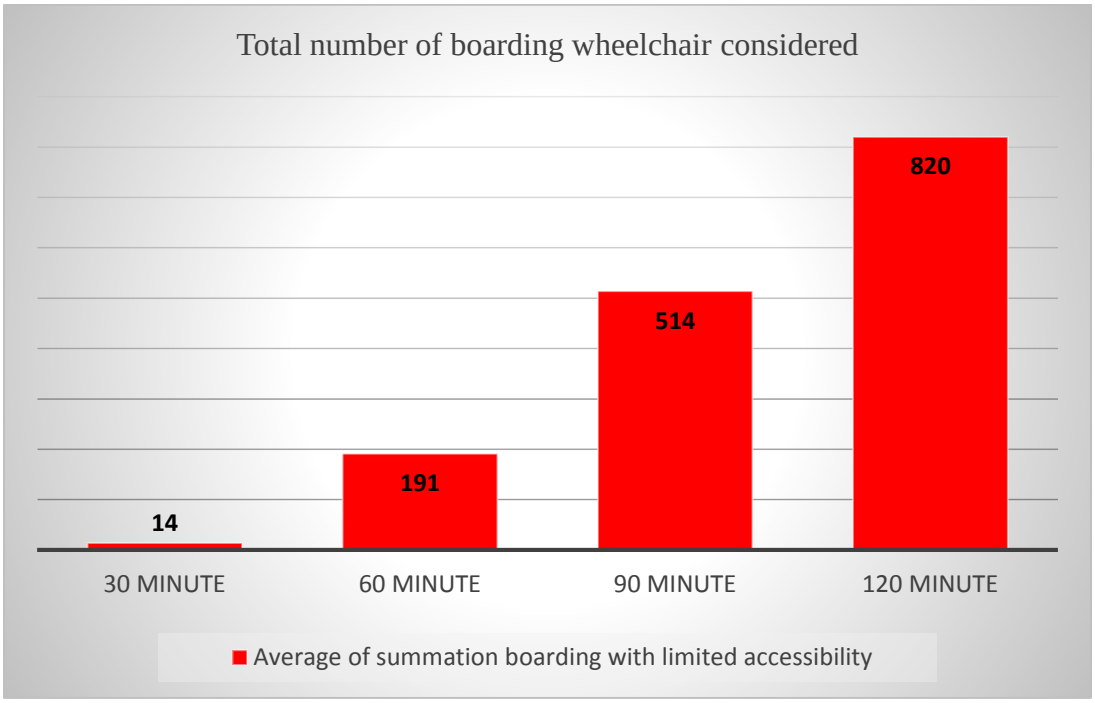



Case two average network access within 60 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Kalamazoo_county
Case Two: With ADA Limitation
AvgPCT_60
0.00 - 0.01
0.02 - 0.17
0.18 - 0.96
0.97 - 3.48
3.49 - 13.91
N
0
3.75
7.5 Miles
Source data United State Census Bureau

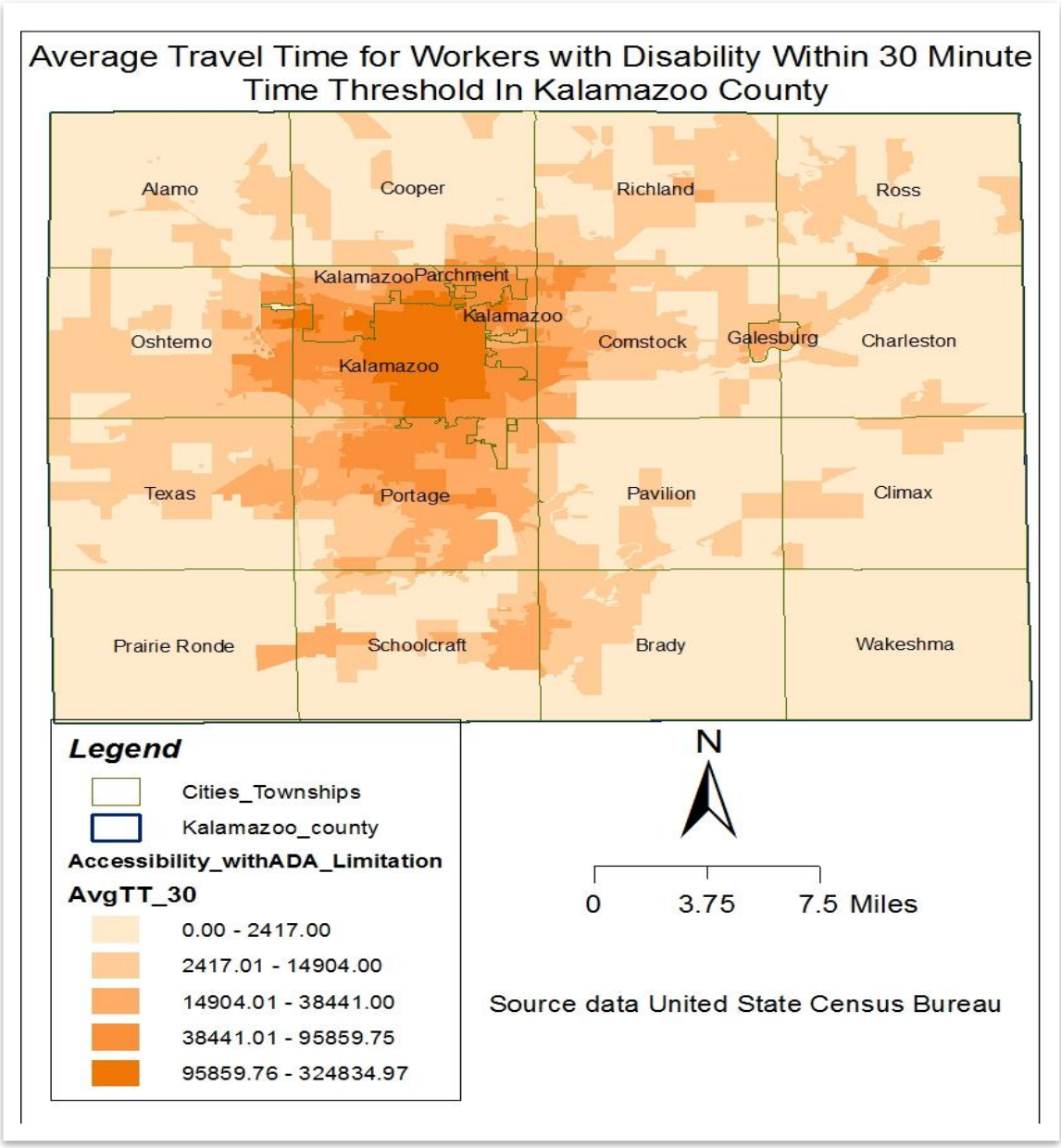

Case two average network access within 90 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
KalamazooParchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Kalamazoo_county
Case Two: With ADA Limitation
AvgPCT_90
0.00 - 0.02
0.03 - 0.19
0.20 - 1.30
1.31 - 3.80
3.81 - 14.32
N
0
3.75
7.5 Miles
Source data United State Census Bureau

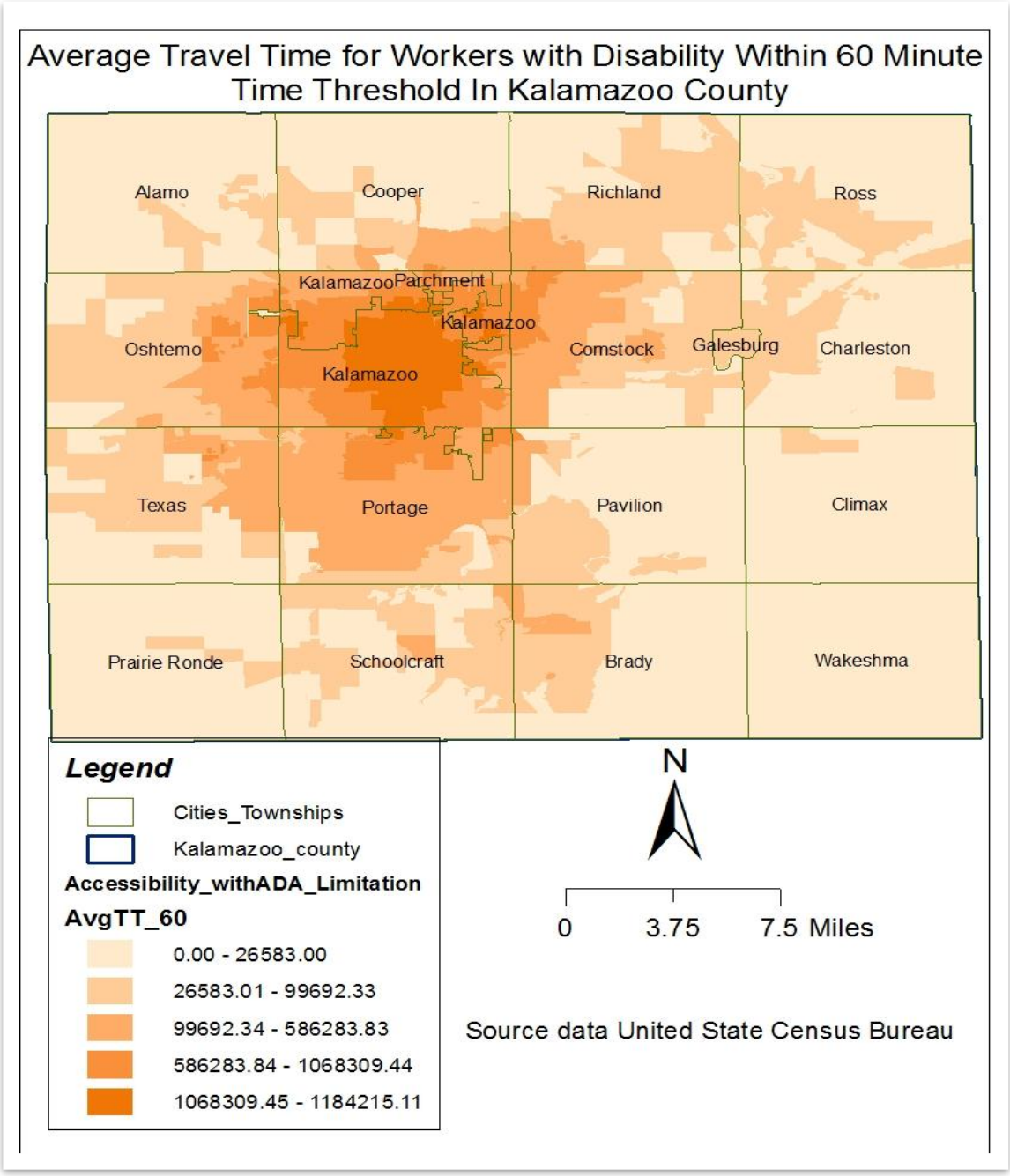

Case two average network access within 120 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Kalamazoo_county
Case Two: With ADA Limitation
AvgPCT_120
0.00 - 0.02
0.03 - 0.22
0.23 - 1.42
1.43 - 3.84
3.85 - 14.37
N
0
3.75
7.5 Miles
Source data United State Census Bureau

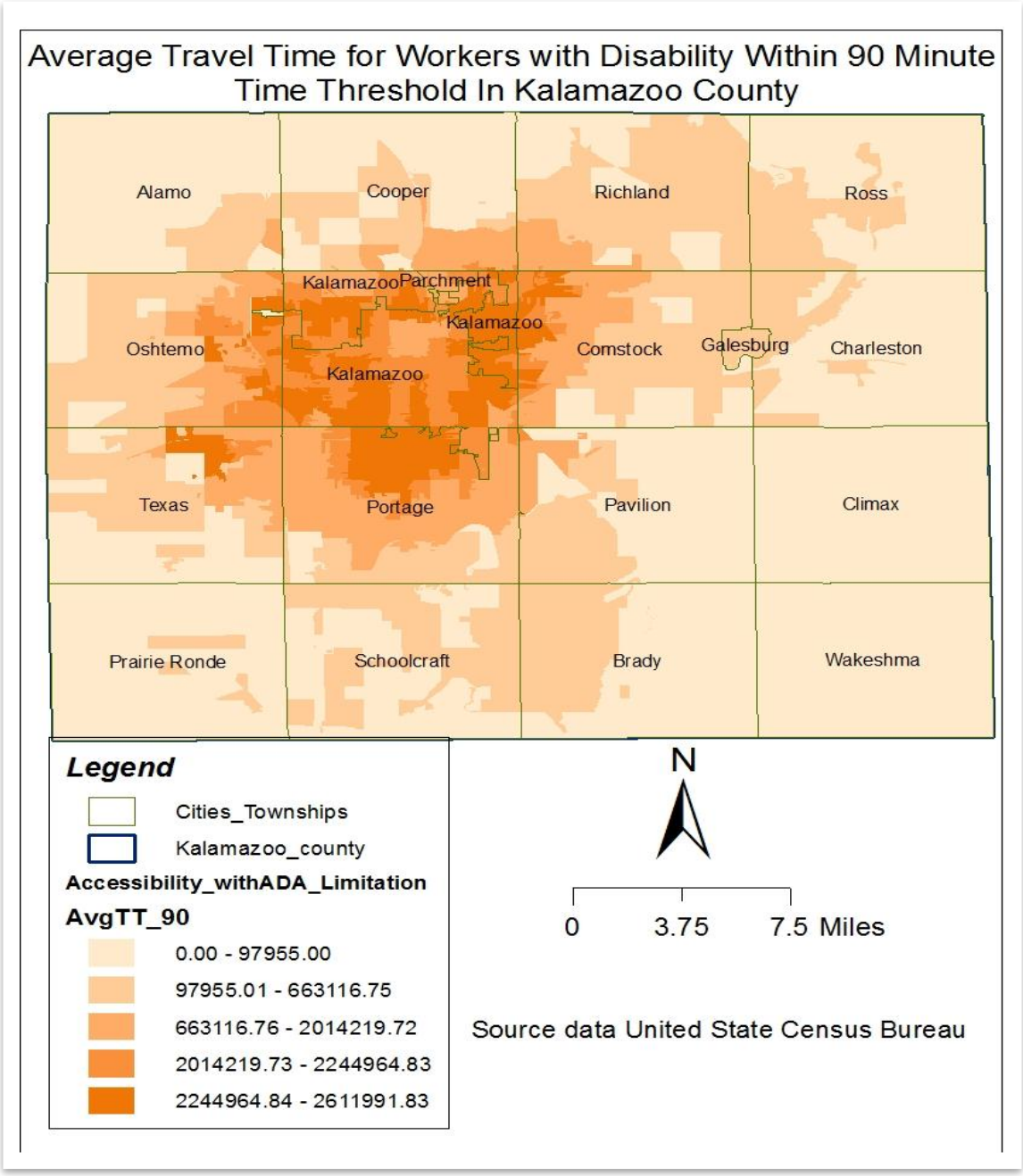
C-3. Total Number of Boarding

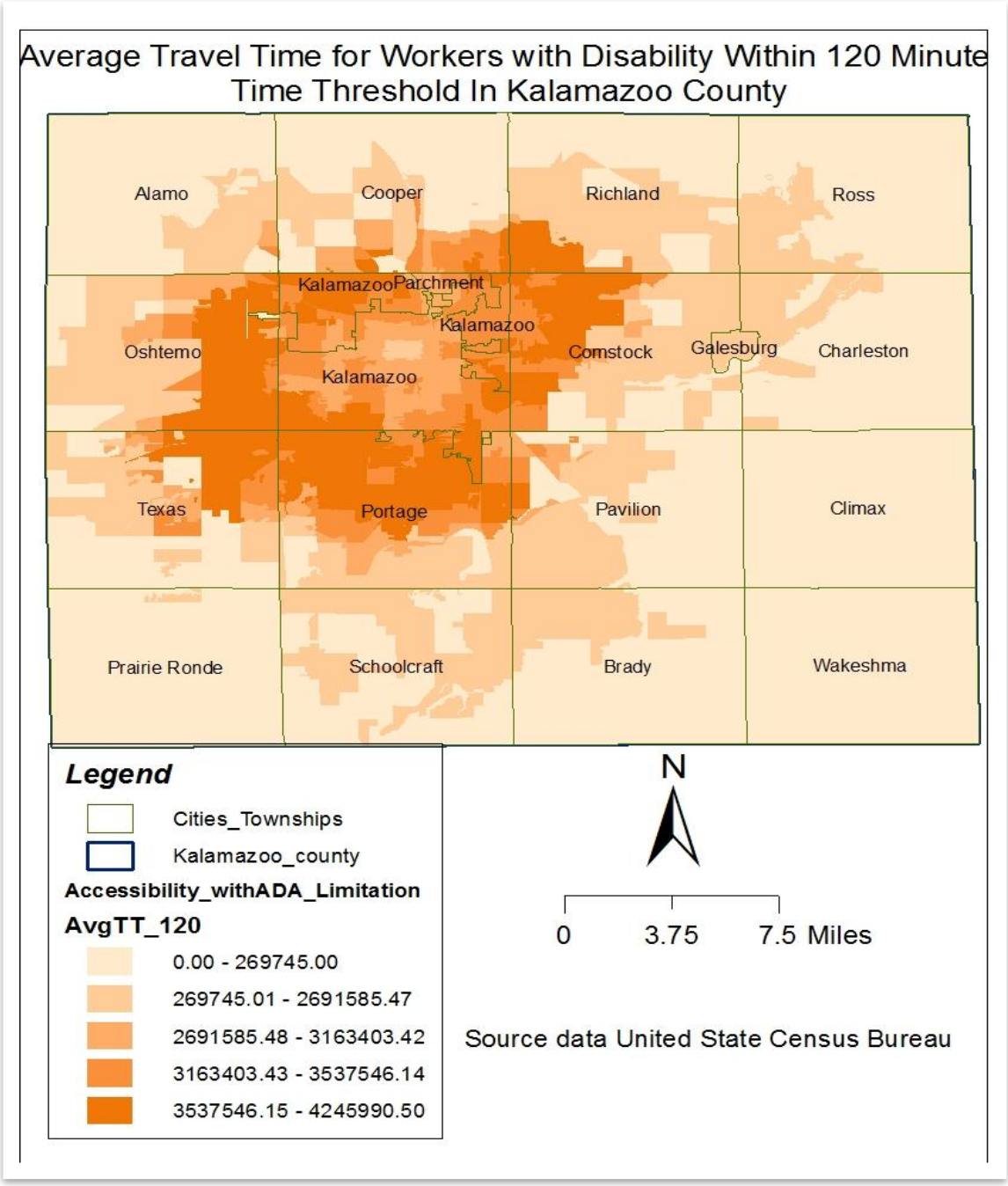


C-4. Average Travel Time

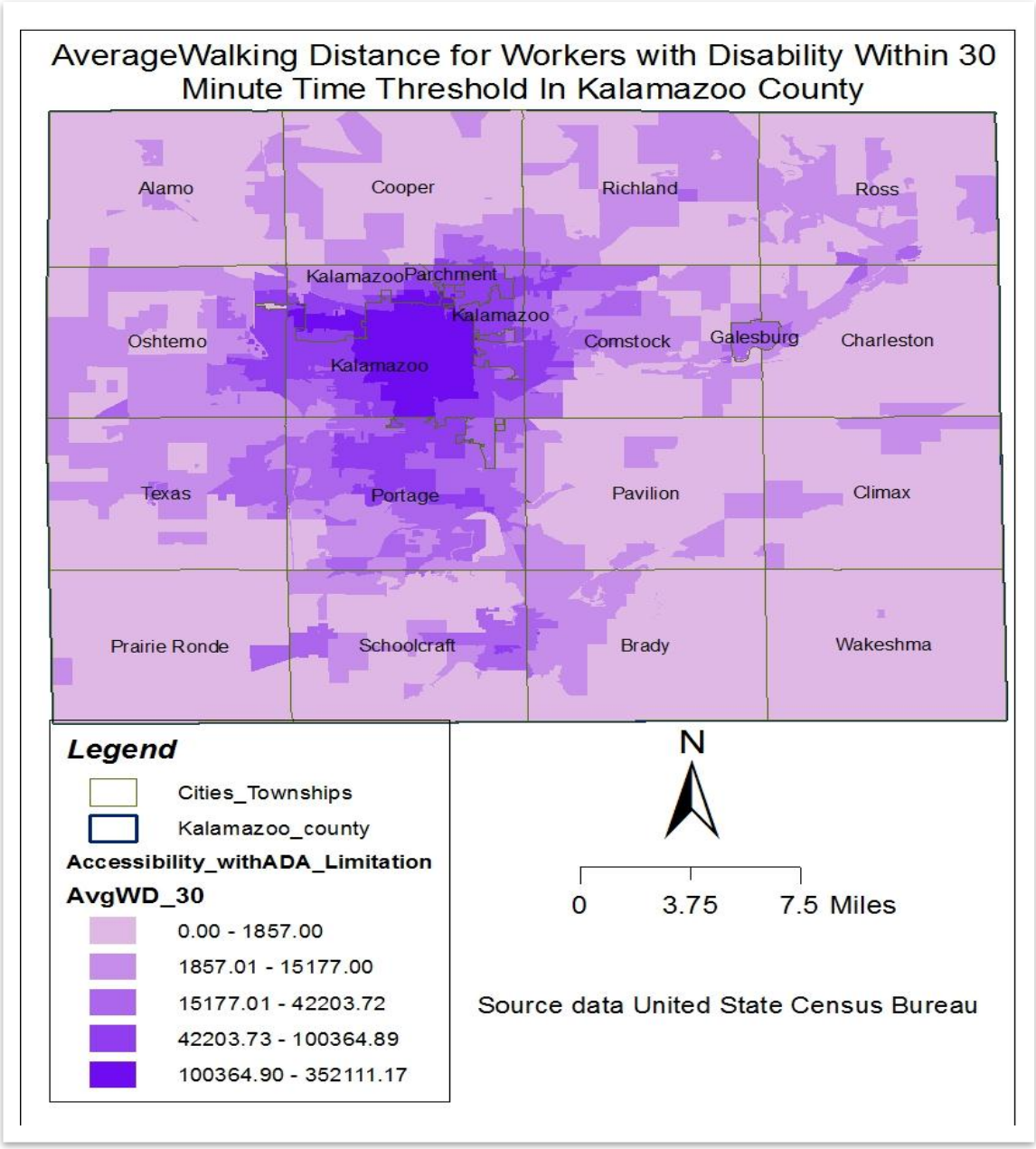


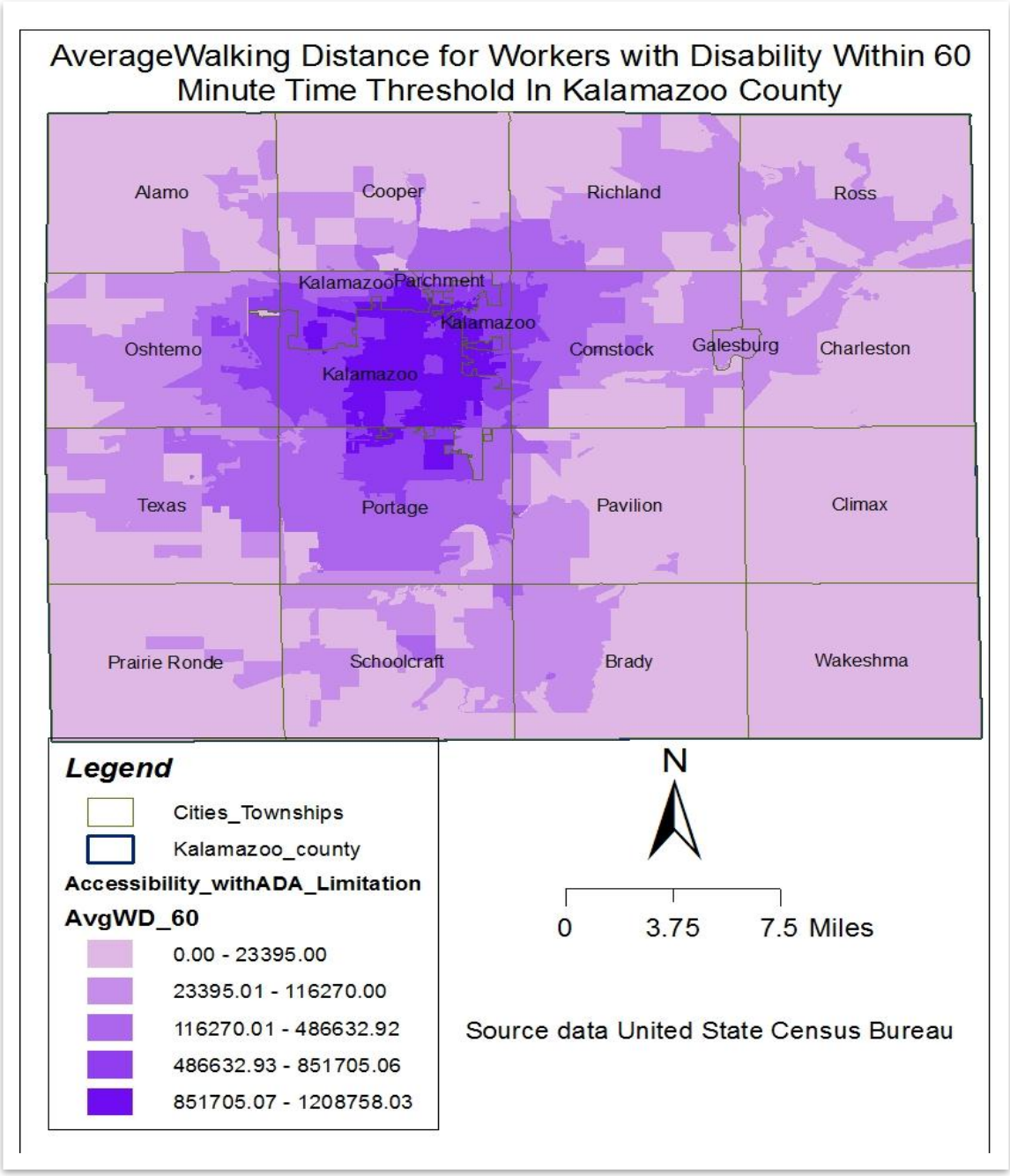

Average Travel Time for Workers with Disability Within 60 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_withADA_Limitation
AvgTT_60
0.00 - 26583.00
26583.01 - 99692.33
99692.34 - 586283.83
586283.84 - 1068309.44
1068309.45 - 1184215.11
N
0
3.75
7.5 Miles
Source data United State Census Bureau

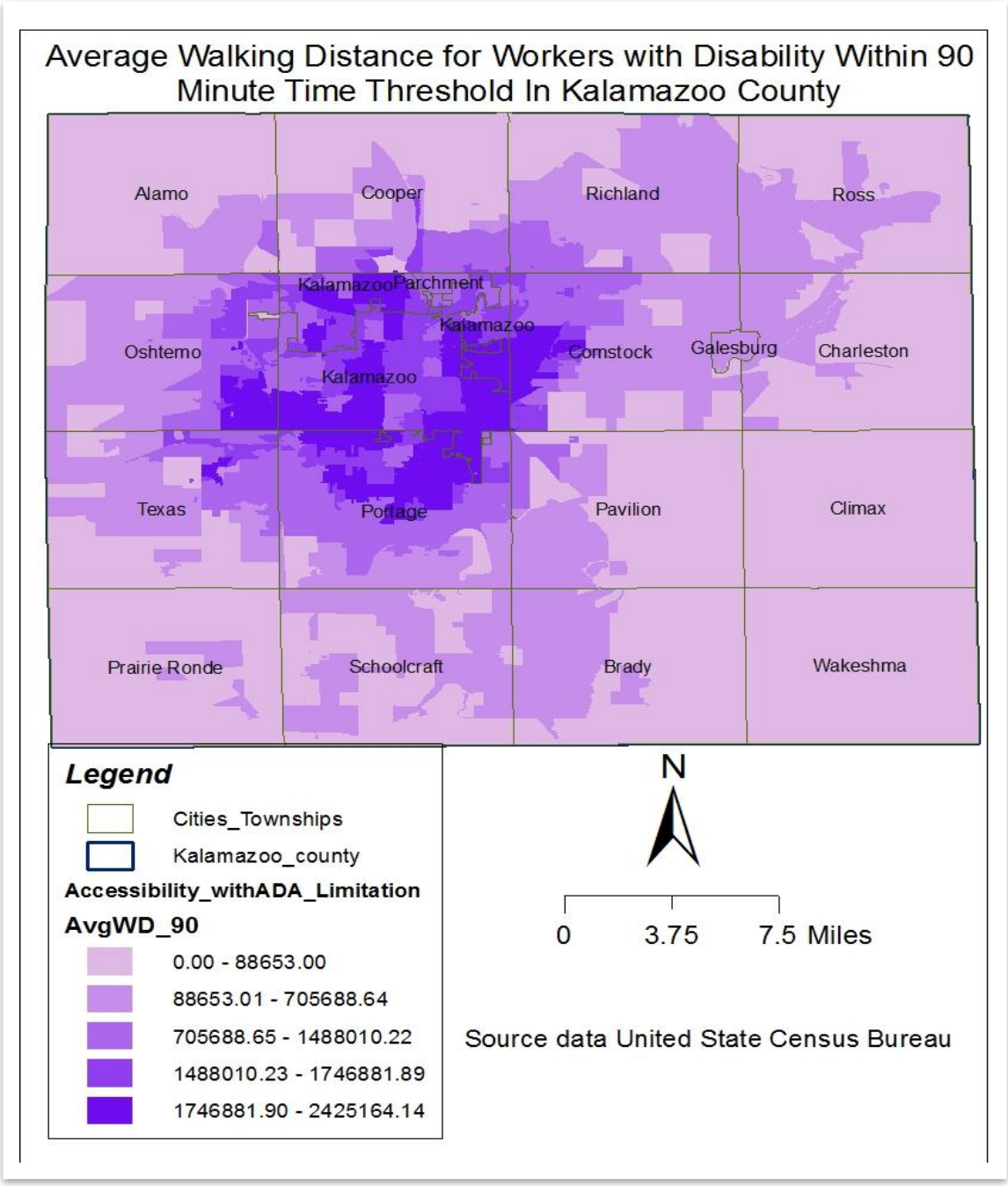

Average Travel Time for Workers with Disability Within 90 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_withADA_Limitation
AvgTT_90
0.00 - 97955.00
97955.01 - 663116.75
663116.76 - 2014219.72
2014219.73 - 2244964.83
2244964.84 - 2611991.83
N
0
3.75
7.5 Miles
Source data United State Census Bureau

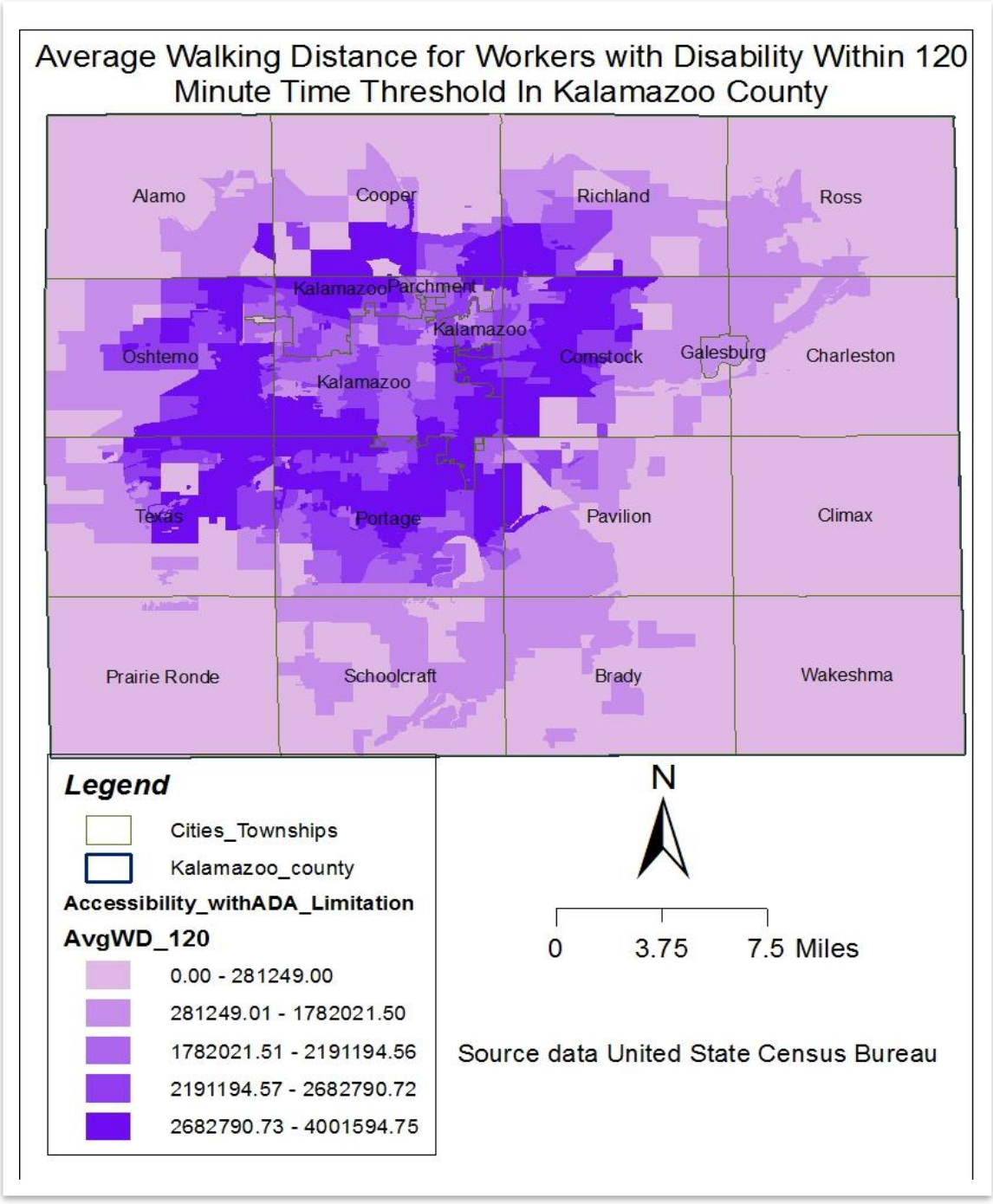

Average Travel Time for Workers with Disability Within 120 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_withADA_Limitation
AvgTT_120
0.00 - 269745.00
269745.01 - 2691585.47
2691585.48 - 3163403.42
3163403.43 - 3537546.14
3537546.15 - 4245990.50
N
0
3.75
7.5 Miles
Source data United State Census Bureau

C-5. Average Walking Distance




AverageWalking Distance for Workers with Disability Within 60 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_withADA_Limitation
AvgWD_60
0.00 - 23395.00
23395.01 - 116270.00
116270.01 - 486632.92
486632.93 - 851705.06
851705.07 - 1208758.03
N
0
3.75
7.5 Miles
Source data United State Census Bureau

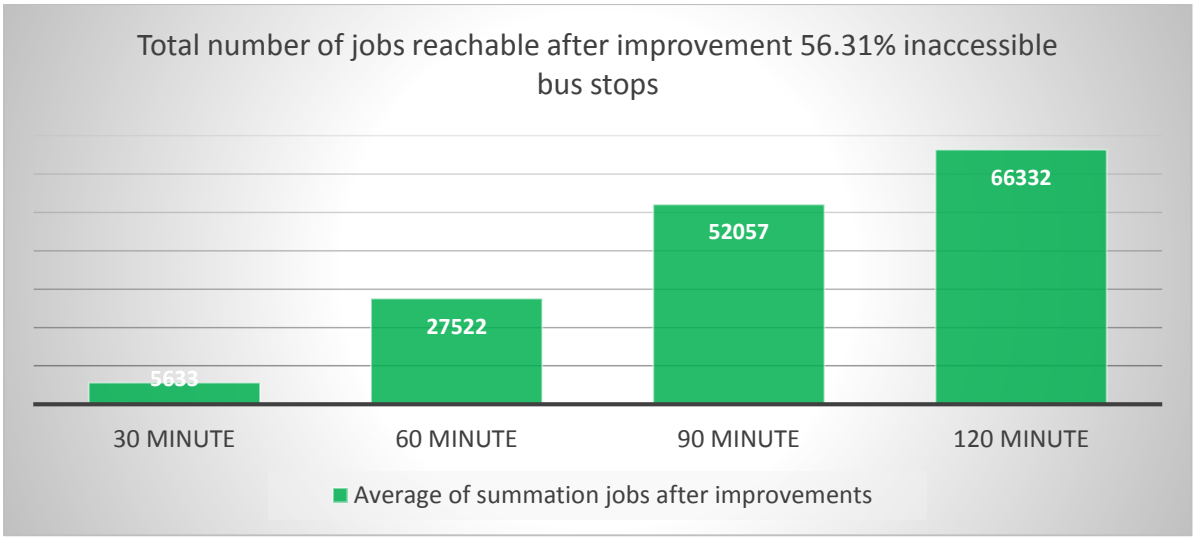

Average Walking Distance for Workers with Disability Within 90 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_withADA_Limitation
AvgWD_90
0.00 - 88653.00
88653.01 - 705688.64
705688.65 - 1488010.22
1488010.23 - 1746881.89
1746881.90 - 2425164.14
N
0
3.75
7.5 Miles
Source data United State Census Bureau


Average Walking Distance for Workers with Disability Within 120 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_withADA_Limitation
AvgWD_120
0.00 - 281249.00
281249.01 - 1782021.50
1782021.51 - 2191194.56
2191194.57 - 2682790.72
2682790.73 - 4001594.75
N
0
3.75
7.5 Miles
Source data United State Census Bureau

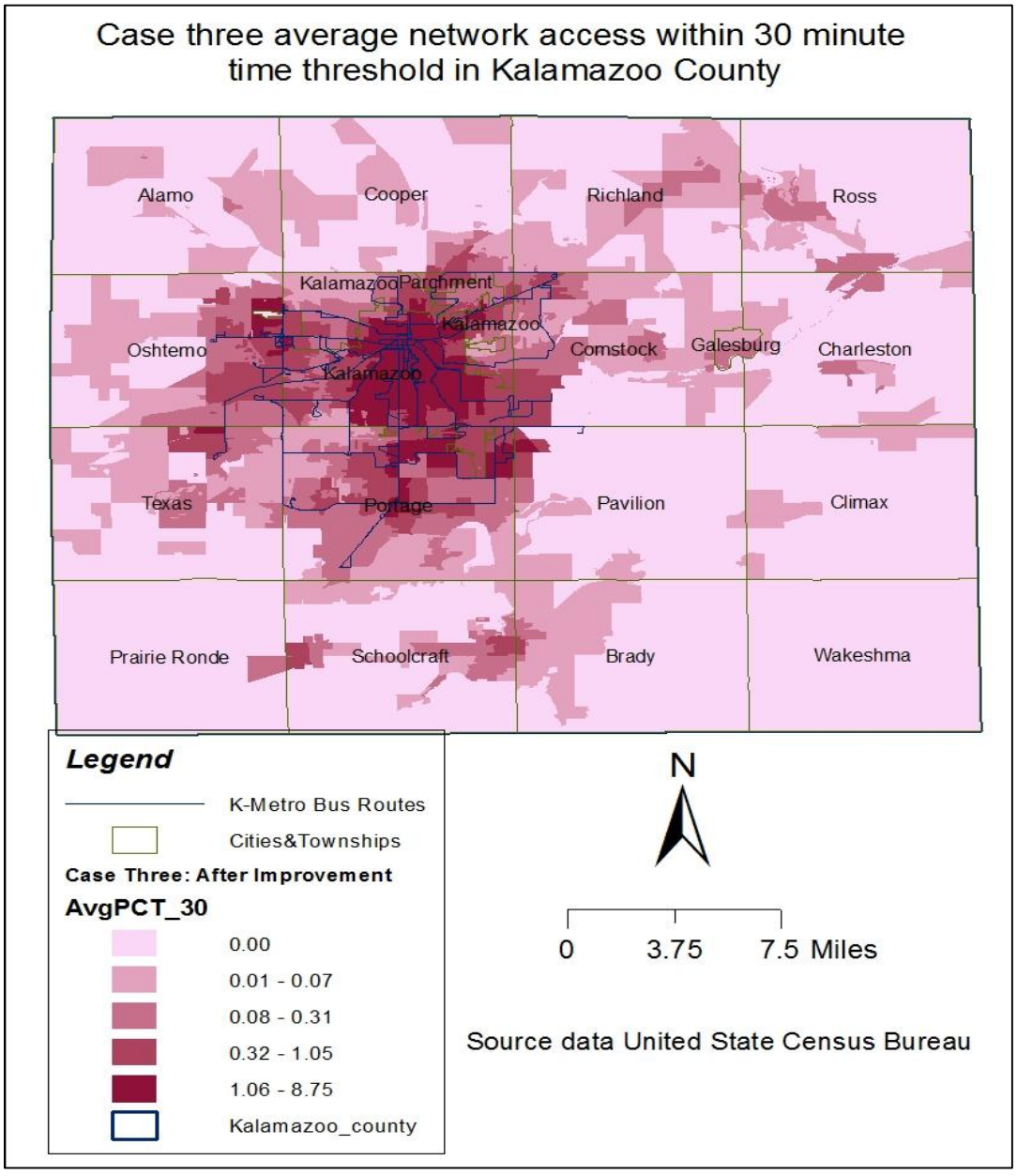
D. Case Three Results: (After Improving Prioritized Bus Stops)

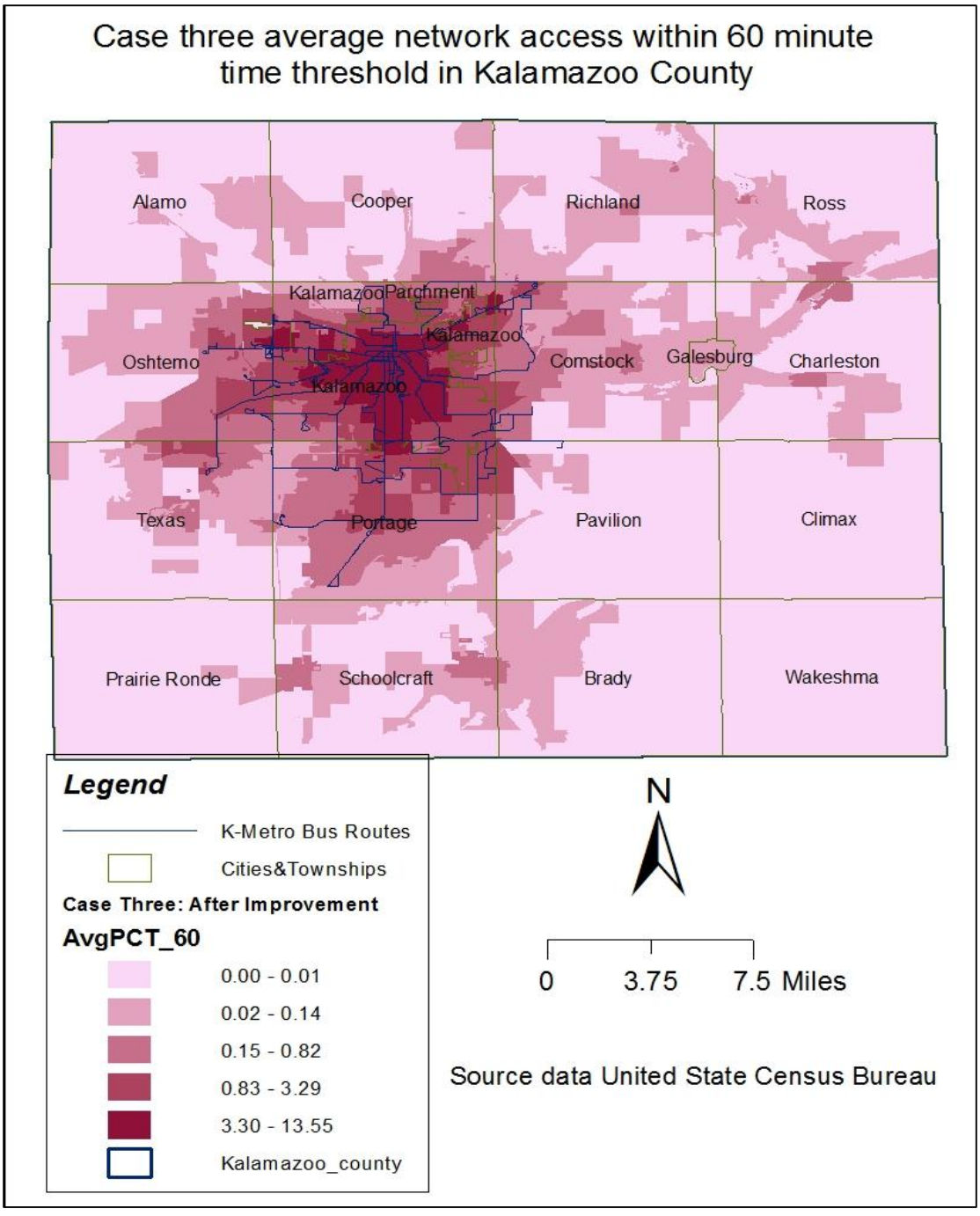
After efficiently and economically prioritizing the improvement of these inaccessible bus stops based on the origin and destination dense areas to solve the ridership problems disable workers have been faced with in Kalamazoo county. The problem appears in Case Two results by looking at number of job opportunity and accessibility reduction, where percentage of reduction was defined as the problem after improving 56.31% total inaccessible bus stops were selected for improvement to show at what percentage the defined problem can be solved. The results were obtained shows an excellent improvement, which are represented as the following sections.

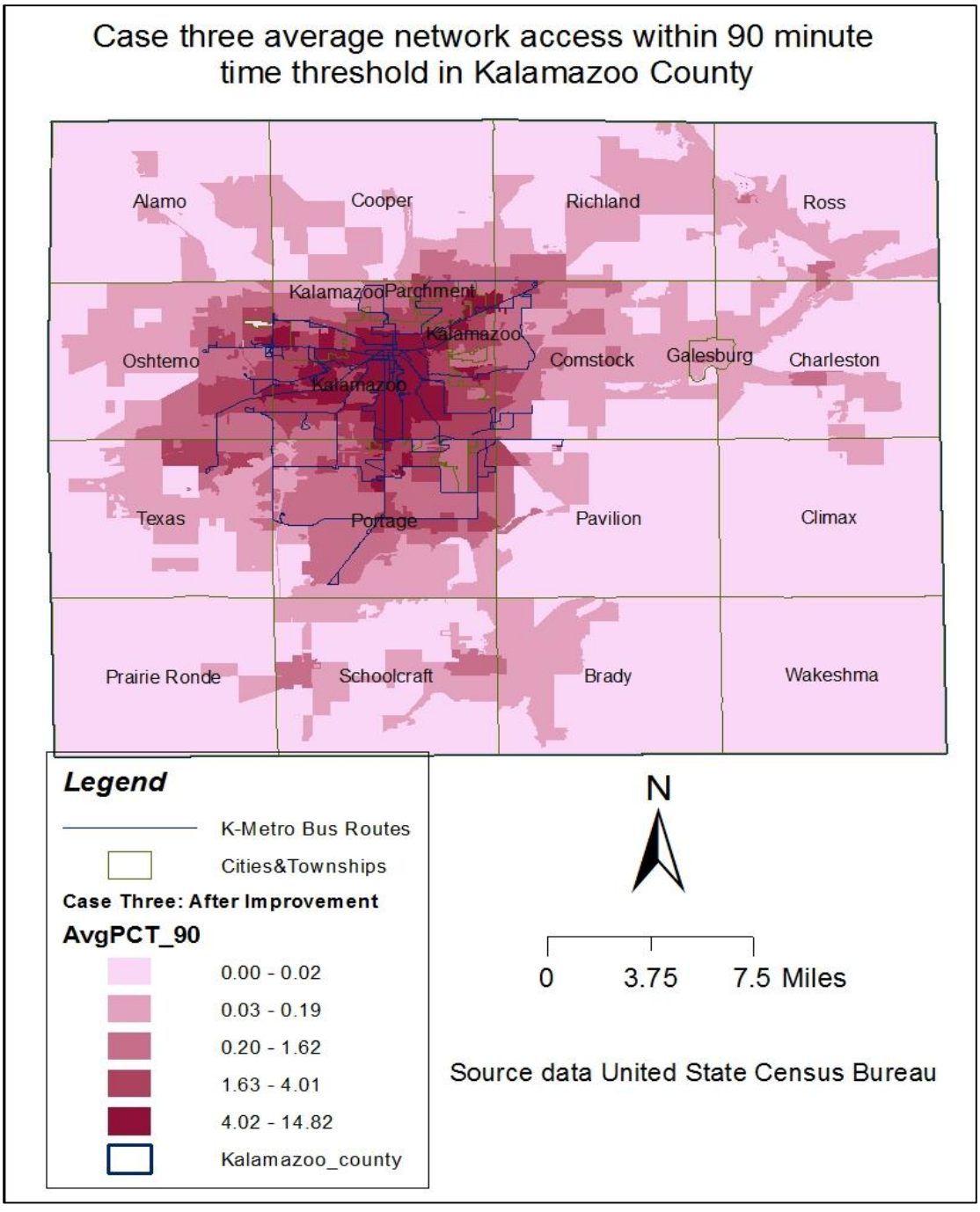
D-1. Total Number of Jobs:

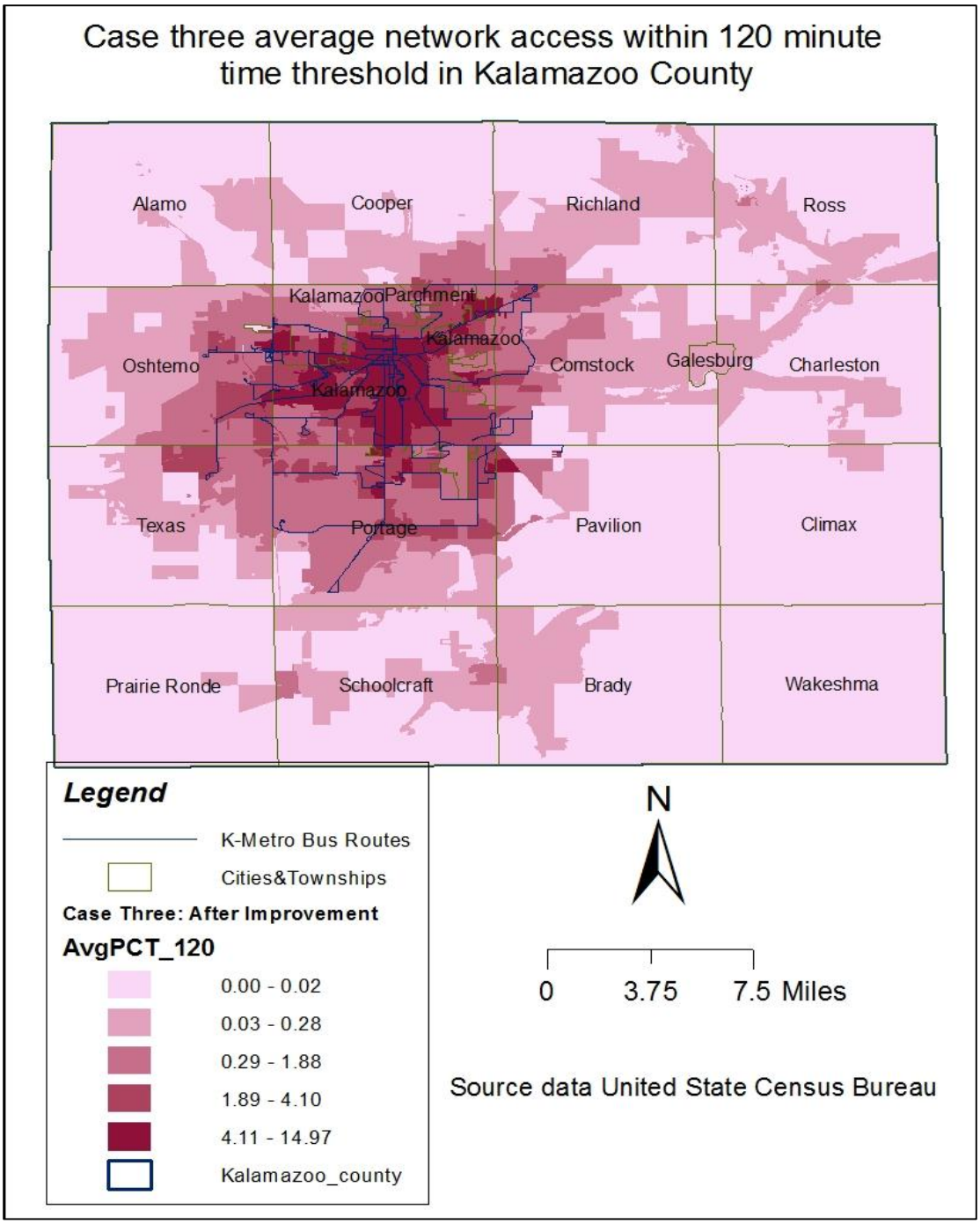


D-2. Average of Network Access (Job Accessibility)

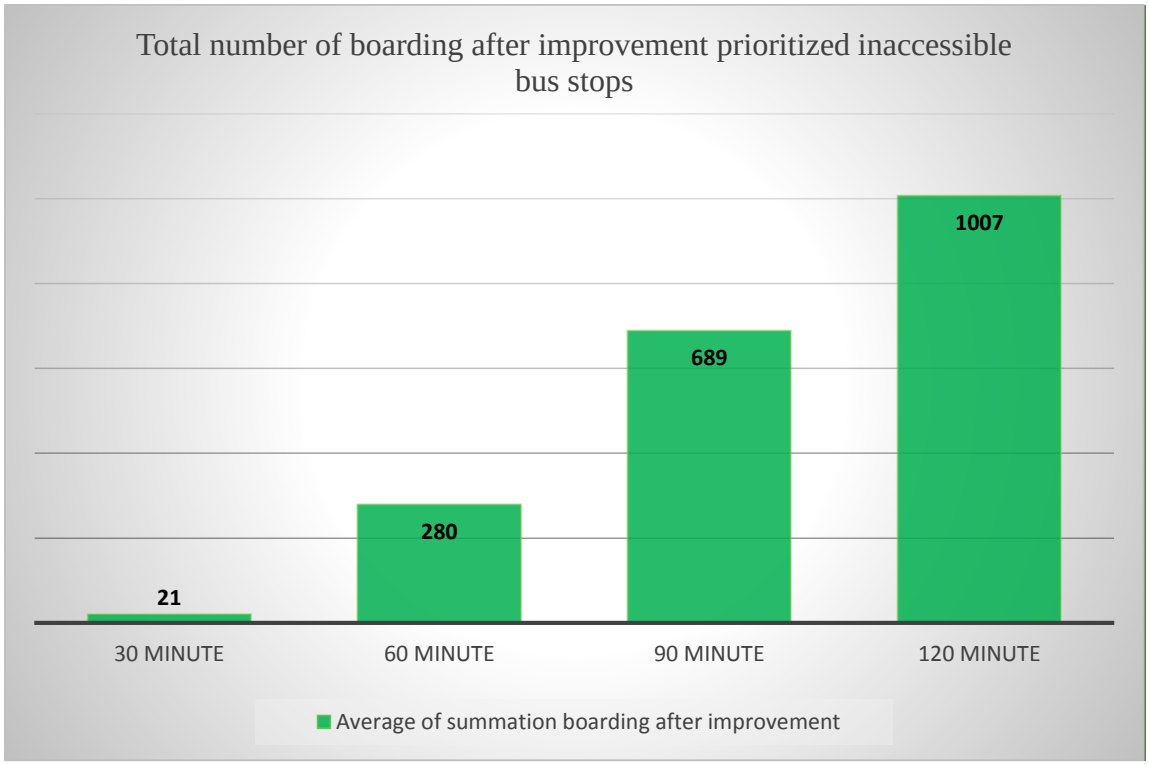



Case three average network access within 60 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Case Three: After Improvement
AvgPCT_60
0.00 - 0.01
0.02 - 0.14
0.15 - 0.82
0.83 - 3.29
3.30 - 13.55
Kalamazoo_county
N
0
3.75
7.5 Miles
Source data United State Census Bureau

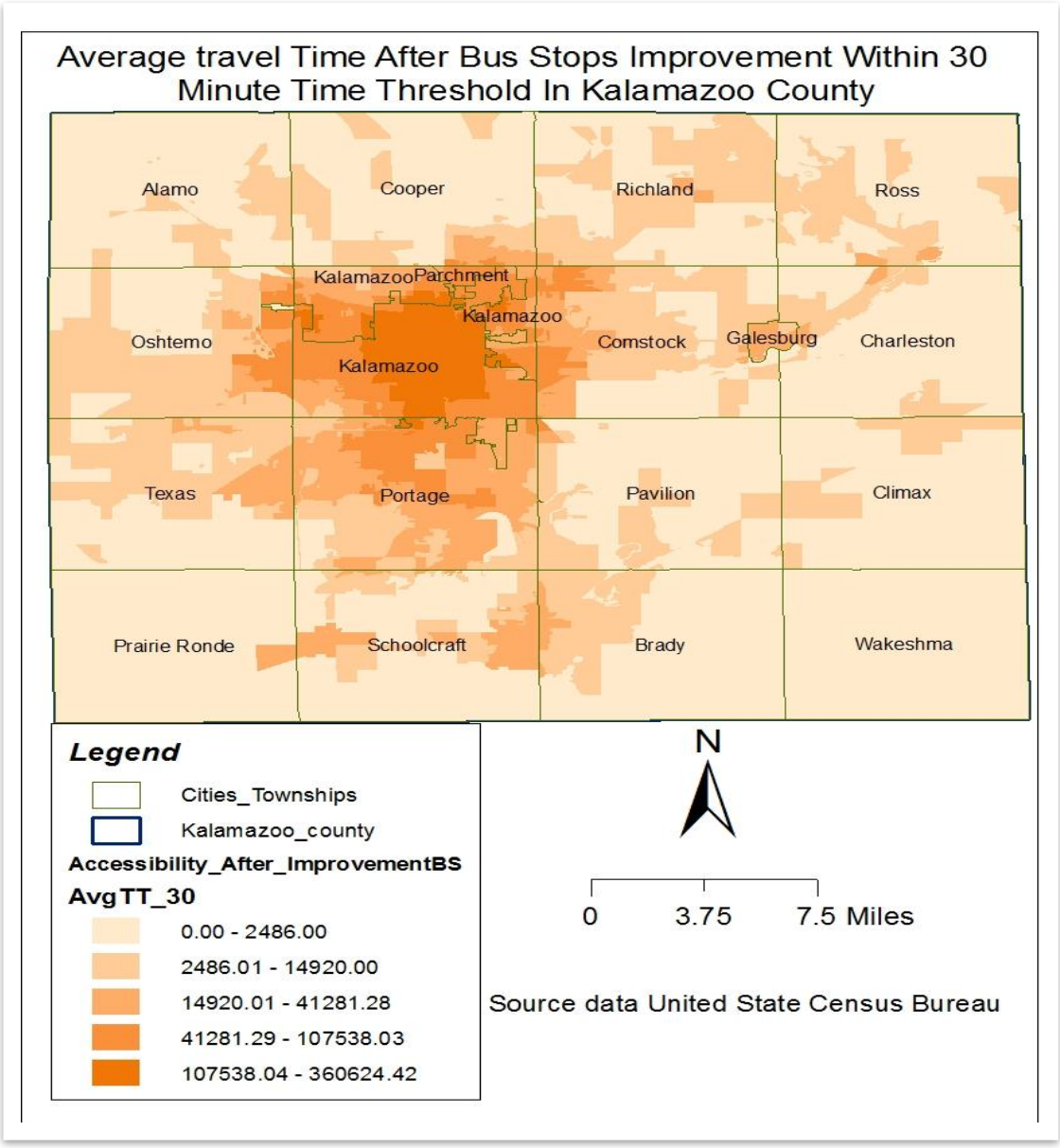

Case three average network access within 90 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Case Three: After Improvement
AvgPCT_90
0.00 - 0.02
0.03 - 0.19
0.20 - 1.62
1.63 - 4.01
4.02 - 14.82
Kalamazoo_county
N
0
3.75
7.5 Miles
Source data United State Census Bureau

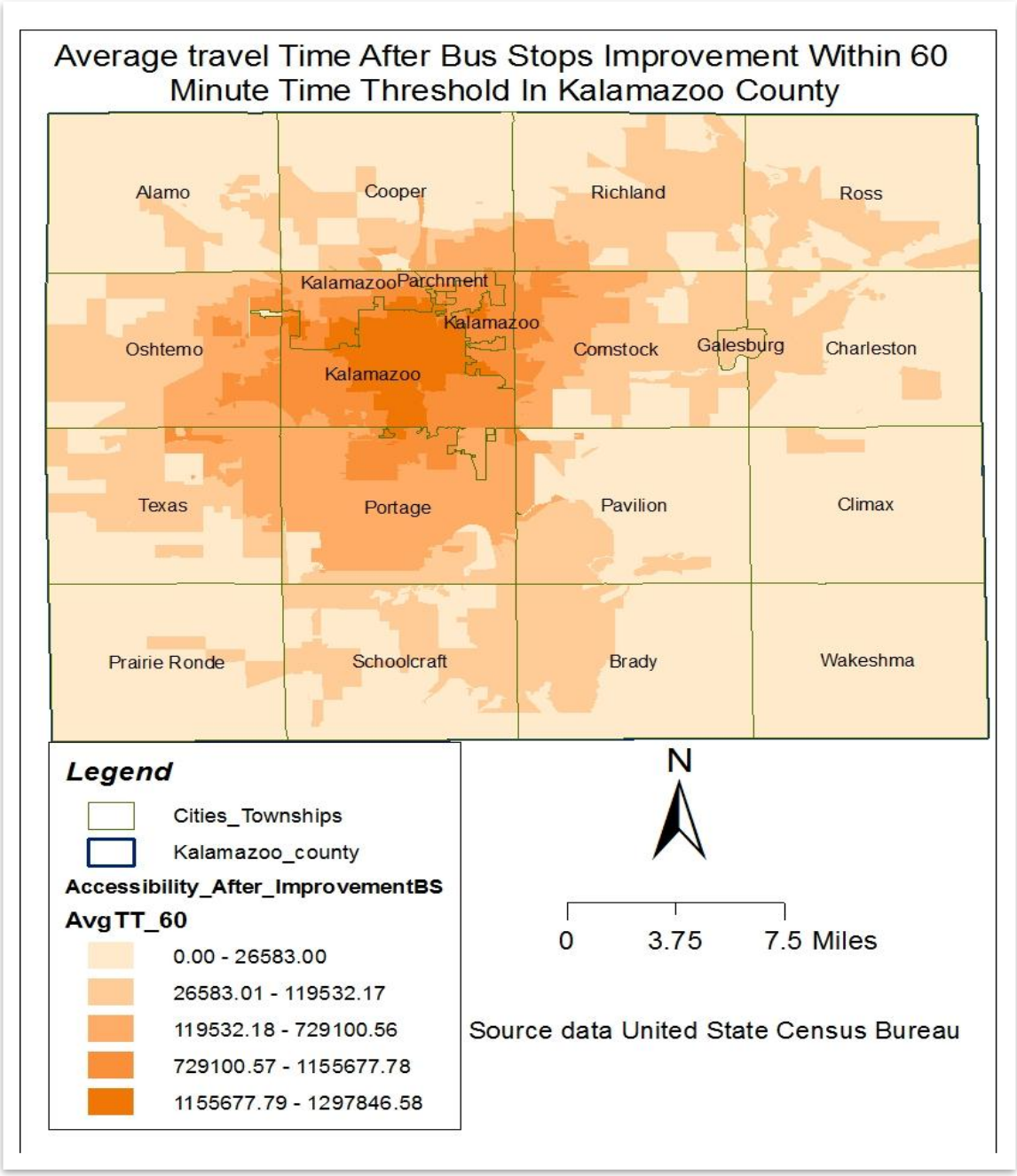

Case three average network access within 120 minute time threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
K-Metro Bus Routes
Cities&Townships
Case Three: After Improvement
AvgPCT_120
0.00 - 0.02
0.03 - 0.28
0.29 - 1.88
1.89 - 4.10
4.11 - 14.97
Kalamazoo_county
N
0
3.75
7.5 Miles
Source data United State Census Bureau

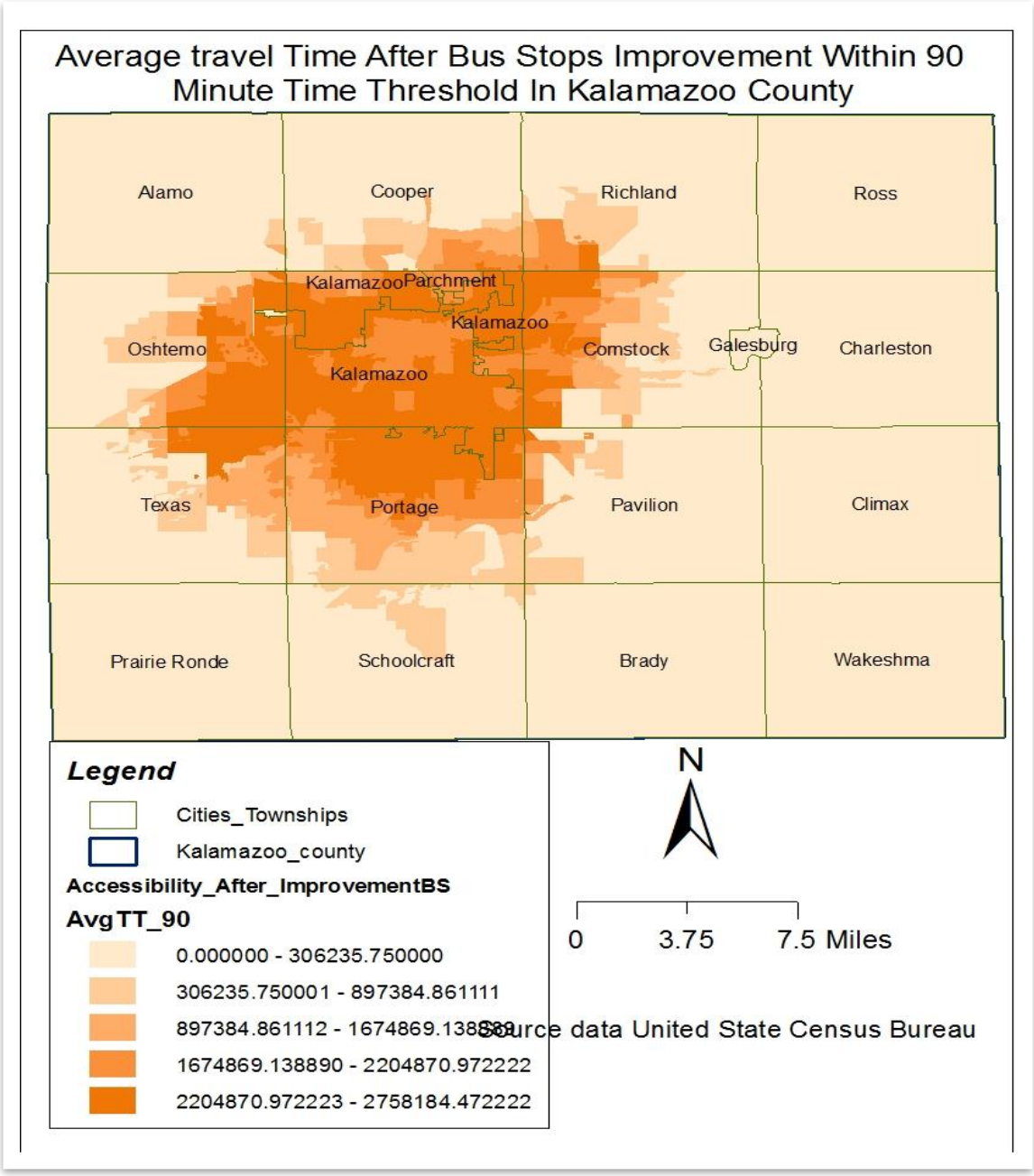
D-3. Total Number of Boarding

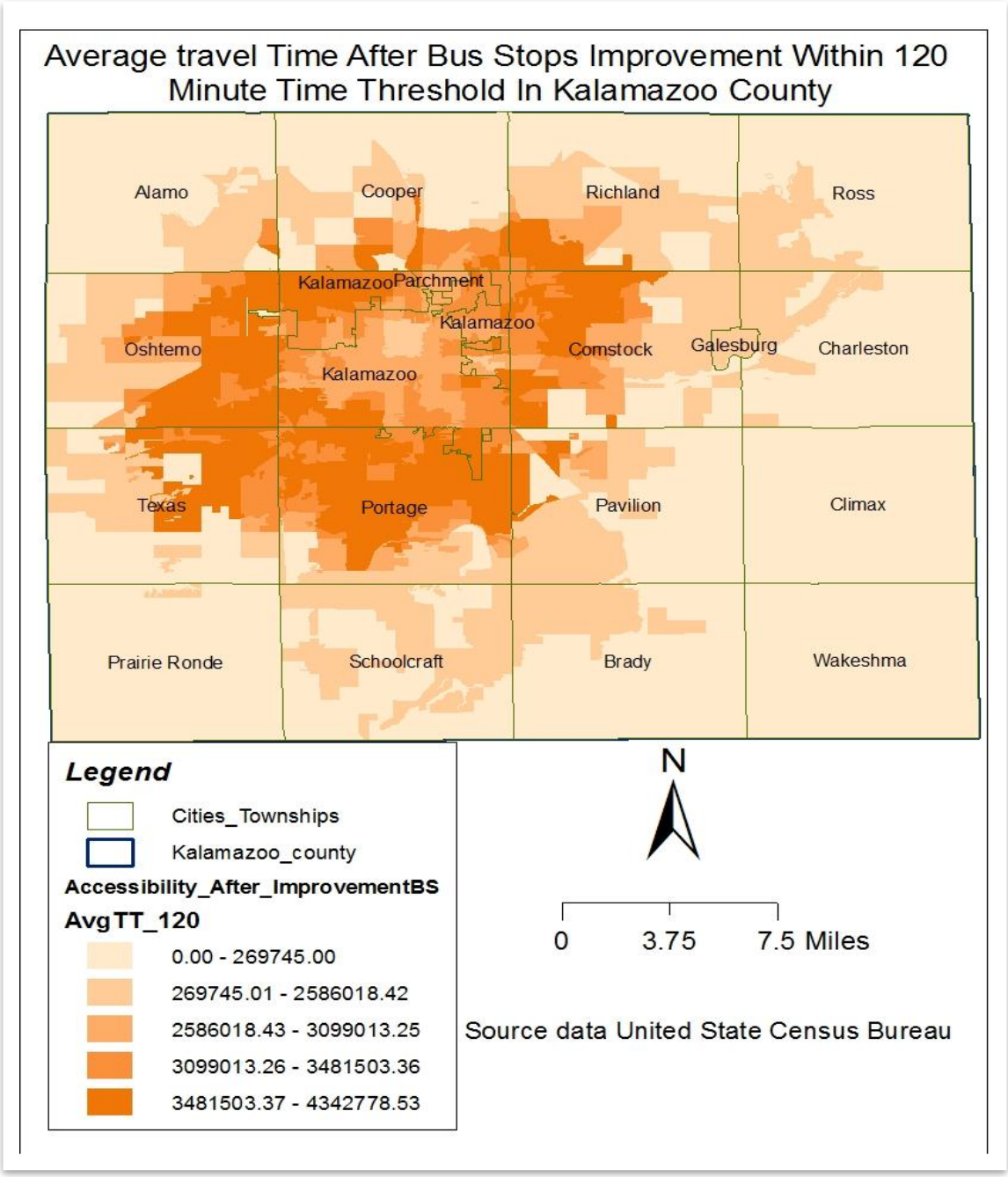


D-4. Average Travel Time

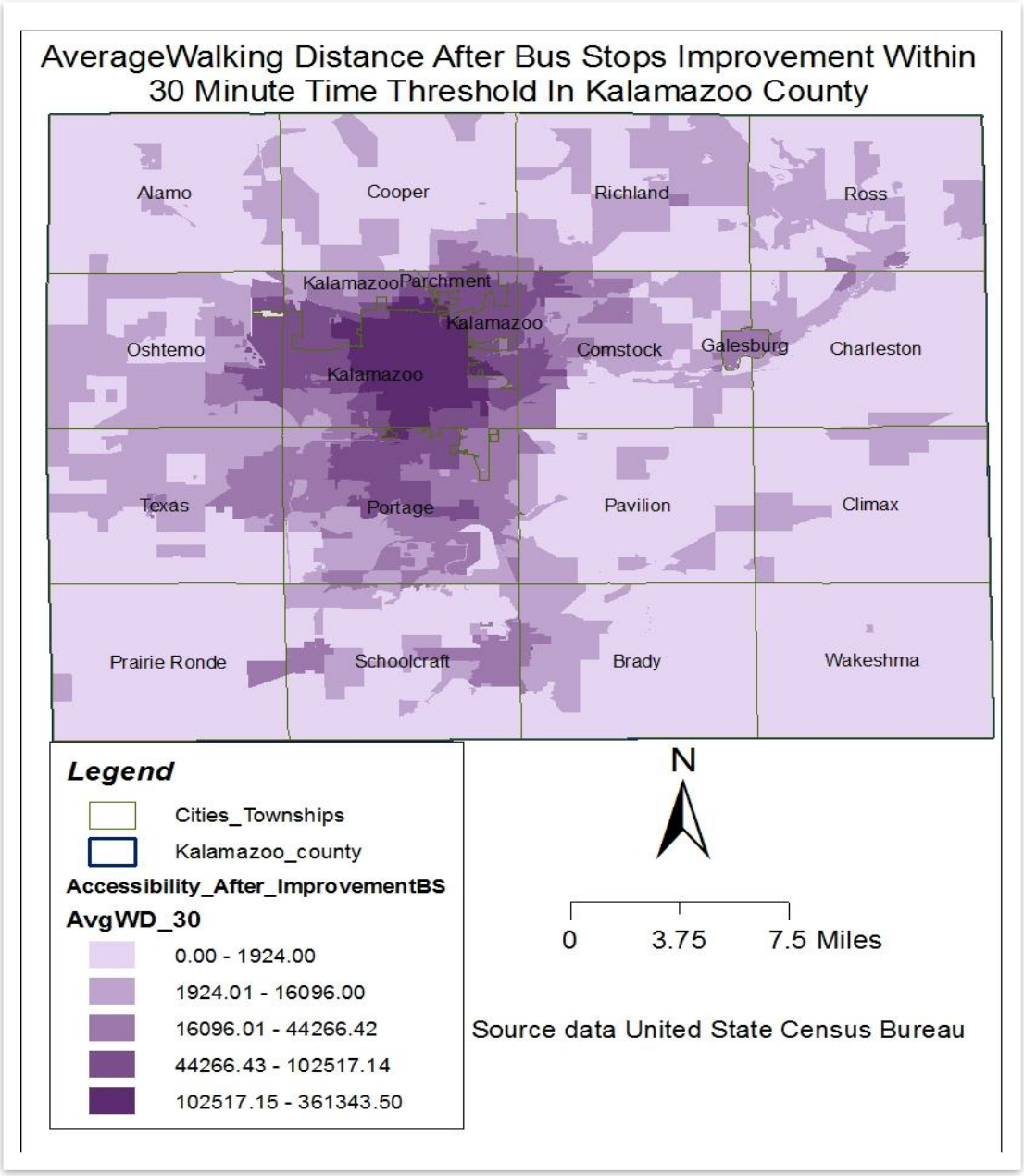


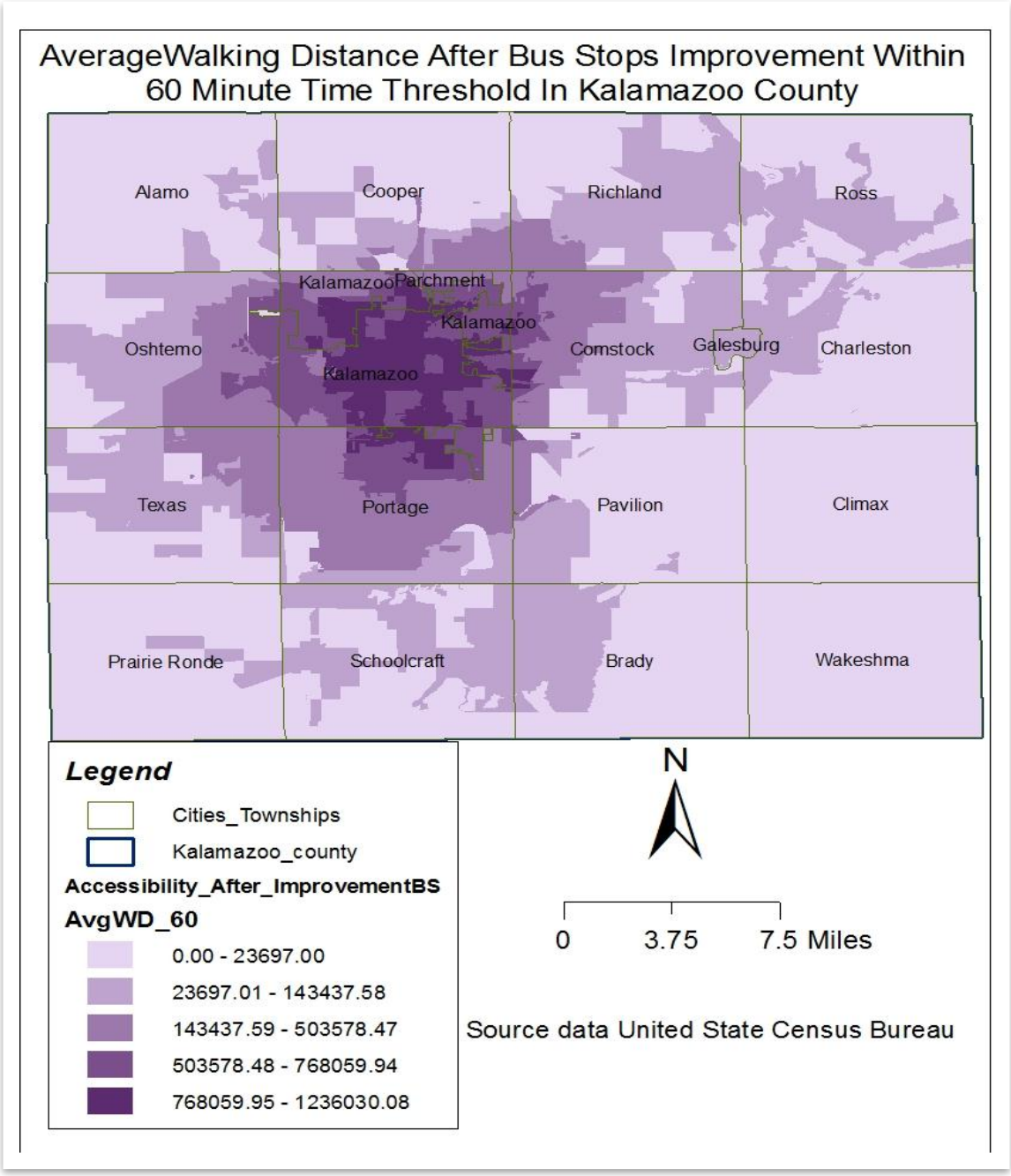

Average travel Time After Bus Stops Improvement Within 60 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_After_ImprovementBS
AvgTT_60
0.00 - 26583.00
26583.01 - 119532.17
119532.18 - 729100.56
729100.57 - 1155677.78
1155677.79 - 1297846.58
N
0
3.75
7.5 Miles
Source data United State Census Bureau

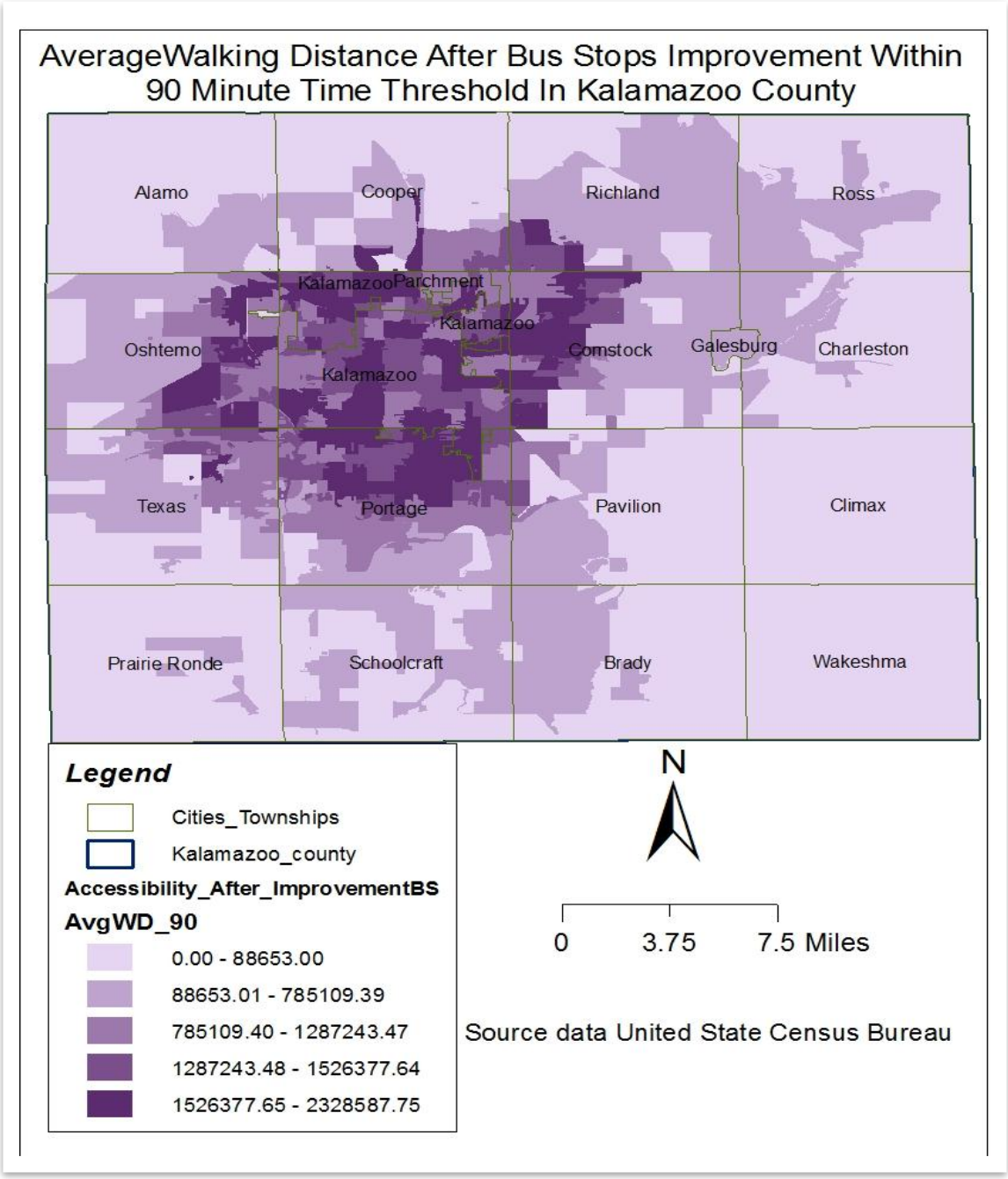

Average travel Time After Bus Stops Improvement Within 90 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_After_ImprovementBS
AvgTT_90
0.000000 - 306235.750000
306235.750001 - 897384.861111
897384.861112 - 1674869.138889
1674869.138890 - 2204870.972222
2204870.972223 - 2758184.472222
N
0
3.75
7.5 Miles
Source data United State Census Bureau

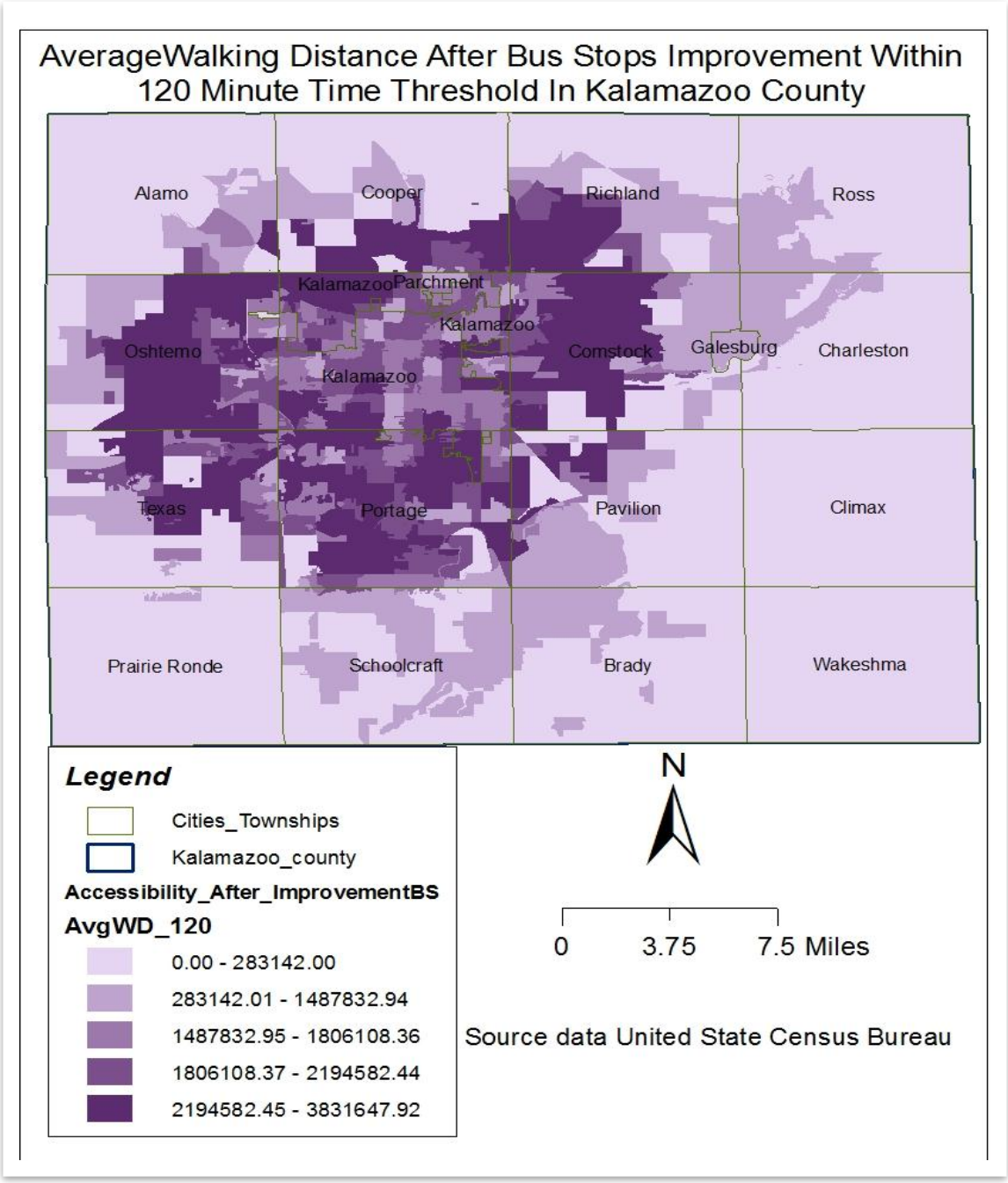

Average travel Time After Bus Stops Improvement Within 120 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_After_ImprovementBS
AvgTT_120
0.00 - 269745.00
269745.01 - 2586018.42
2586018.43 - 3099013.25
3099013.26 - 3481503.36
3481503.37 - 4342778.53
N
0
3.75
7.5 Miles
Source data United State Census Bureau

D-5. Average Walking Distance



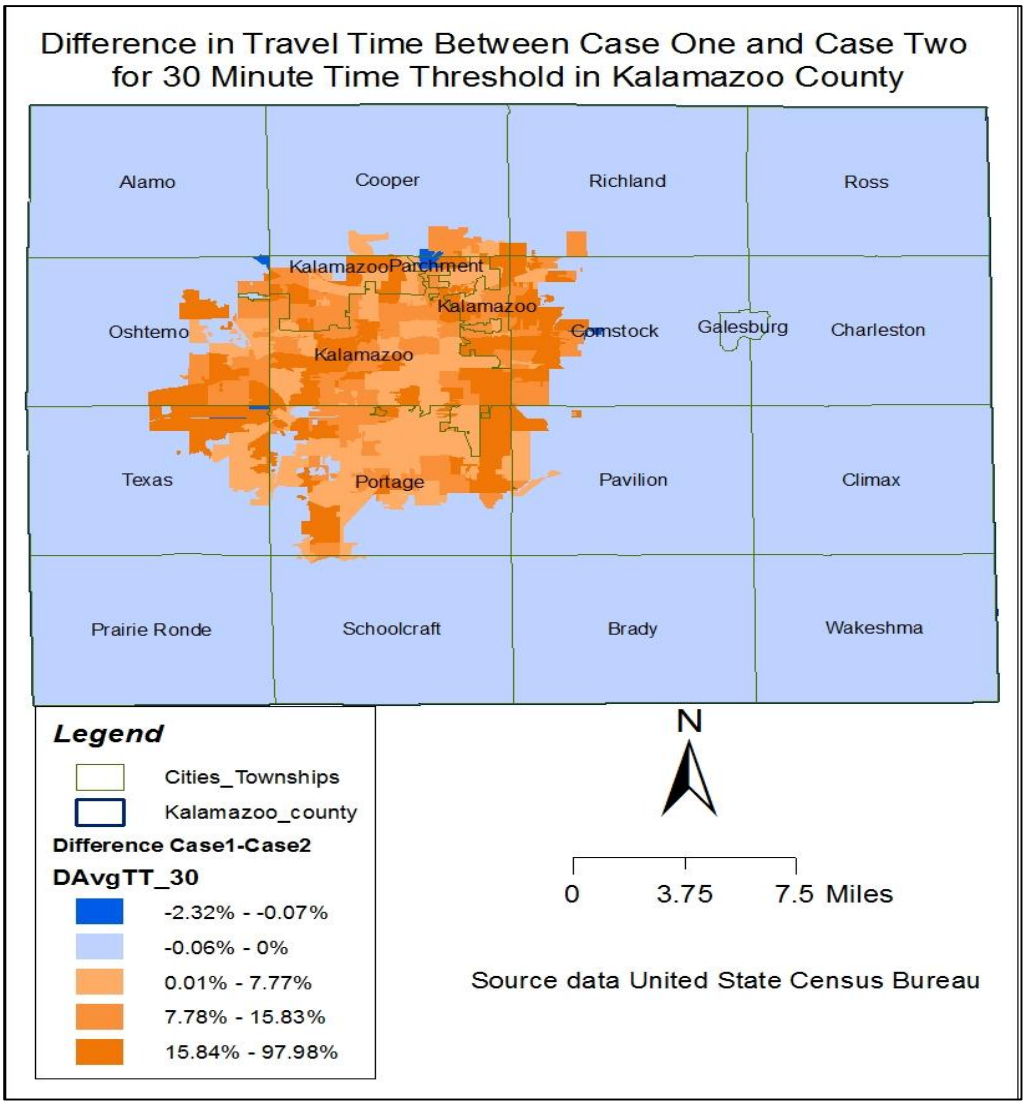

AverageWalking Distance After Bus Stops Improvement Within 60 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Kalamazoo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_After_ImprovementBS
AvgWD_60
0.00 - 23697.00
23697.01 - 143437.58
143437.59 - 503578.47
503578.48 - 768059.94
768059.95 - 1236030.08
N
0
3.75
7.5 Miles
Source data United State Census Bureau

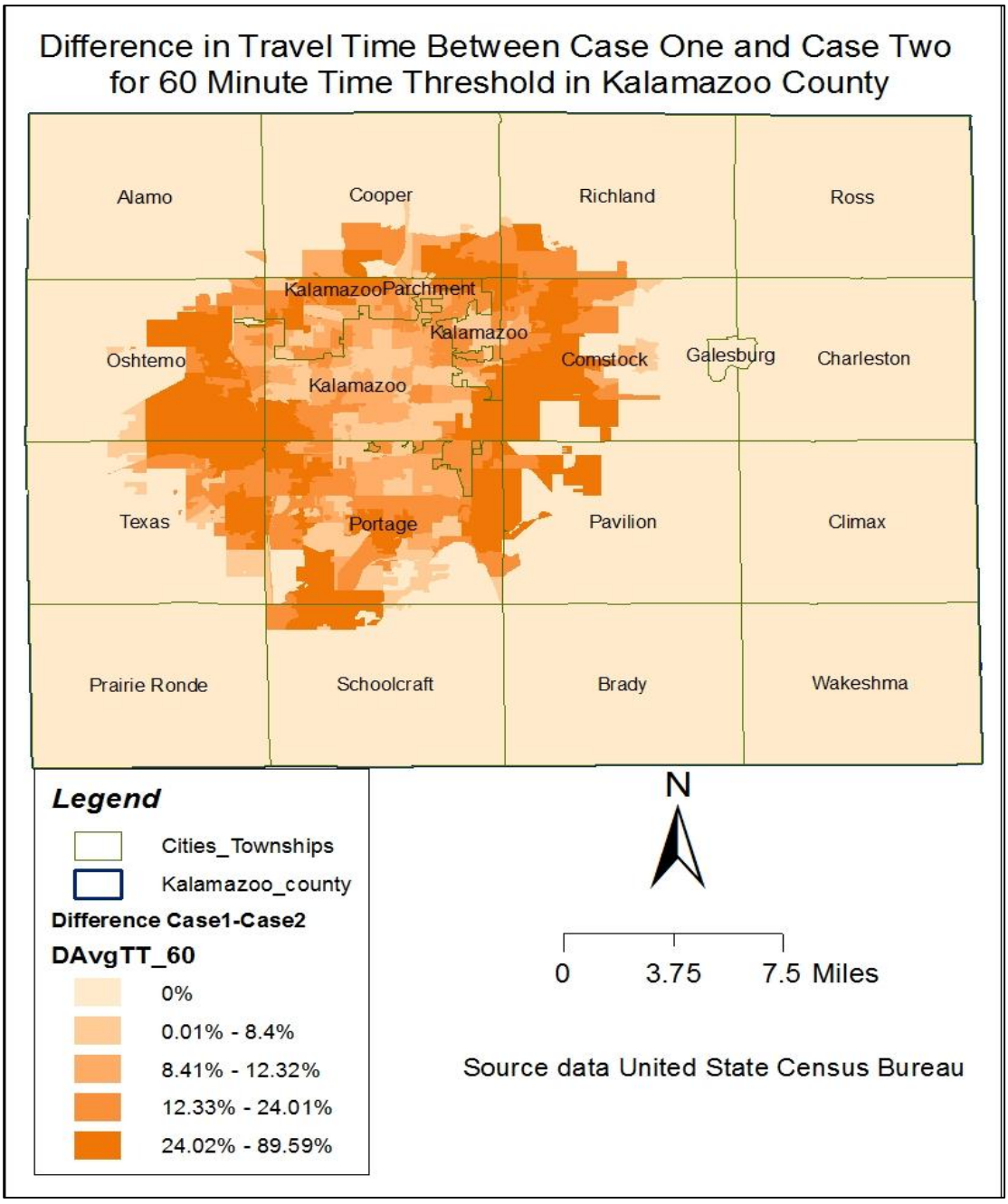

AverageWalking Distance After Bus Stops Improvement Within 90 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_After_ImprovementBS
AvgWD_90
0.00 - 88653.00
88653.01 - 785109.39
785109.40 - 1287243.47
1287243.48 - 1526377.64
1526377.65 - 2328587.75
N
0
3.75
7.5 Miles
Source data United State Census Bureau

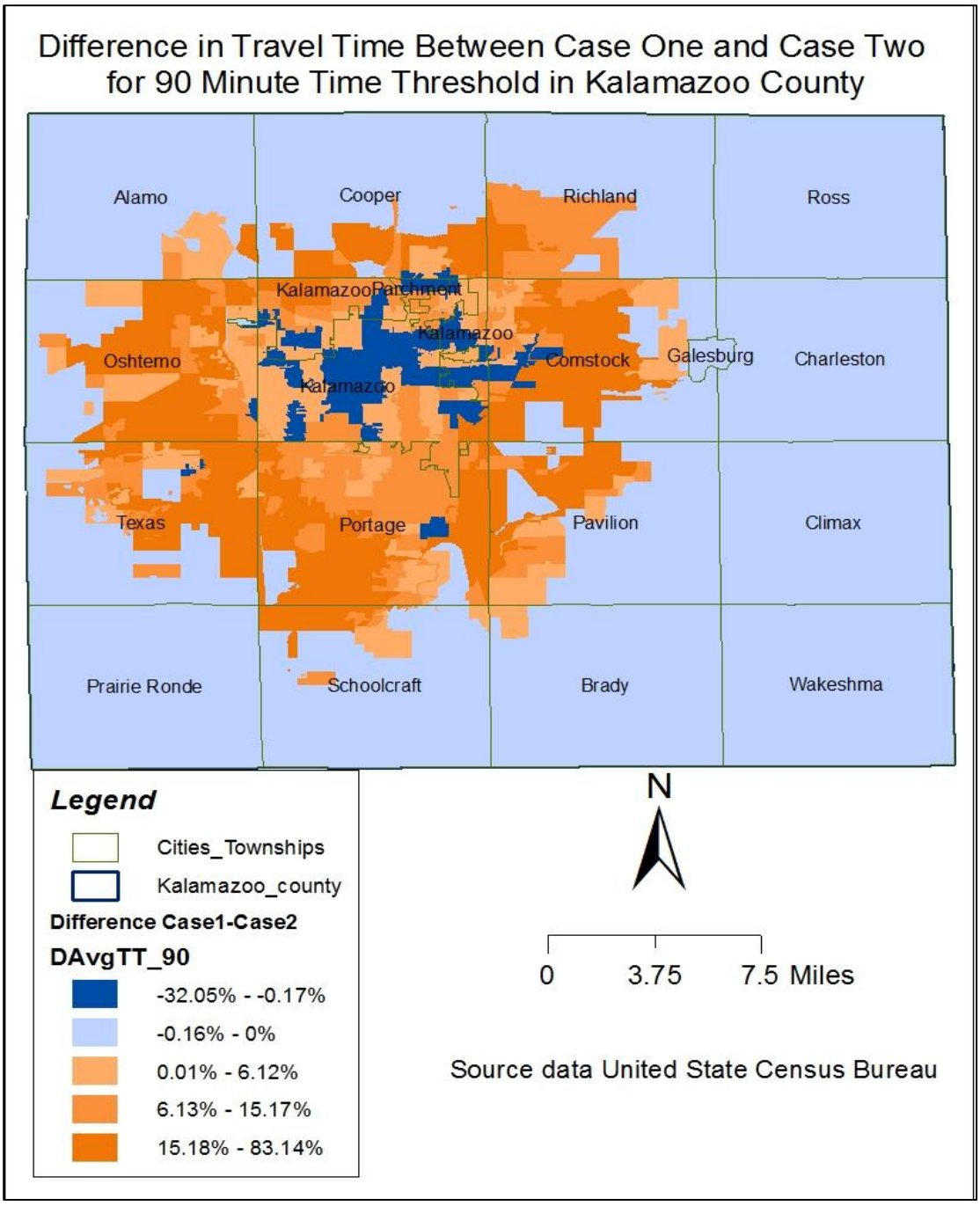

AverageWalking Distance After Bus Stops Improvement Within 120 Minute Time Threshold In Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Accessibility_After_ImprovementBS
AvgWD_120
0.00 - 283142.00
283142.01 - 1487832.94
1487832.95 - 1806108.36
1806108.37 - 2194582.44
2194582.45 - 3831647.92
N
0
3.75
7.5 Miles
Source data United State Census Bureau

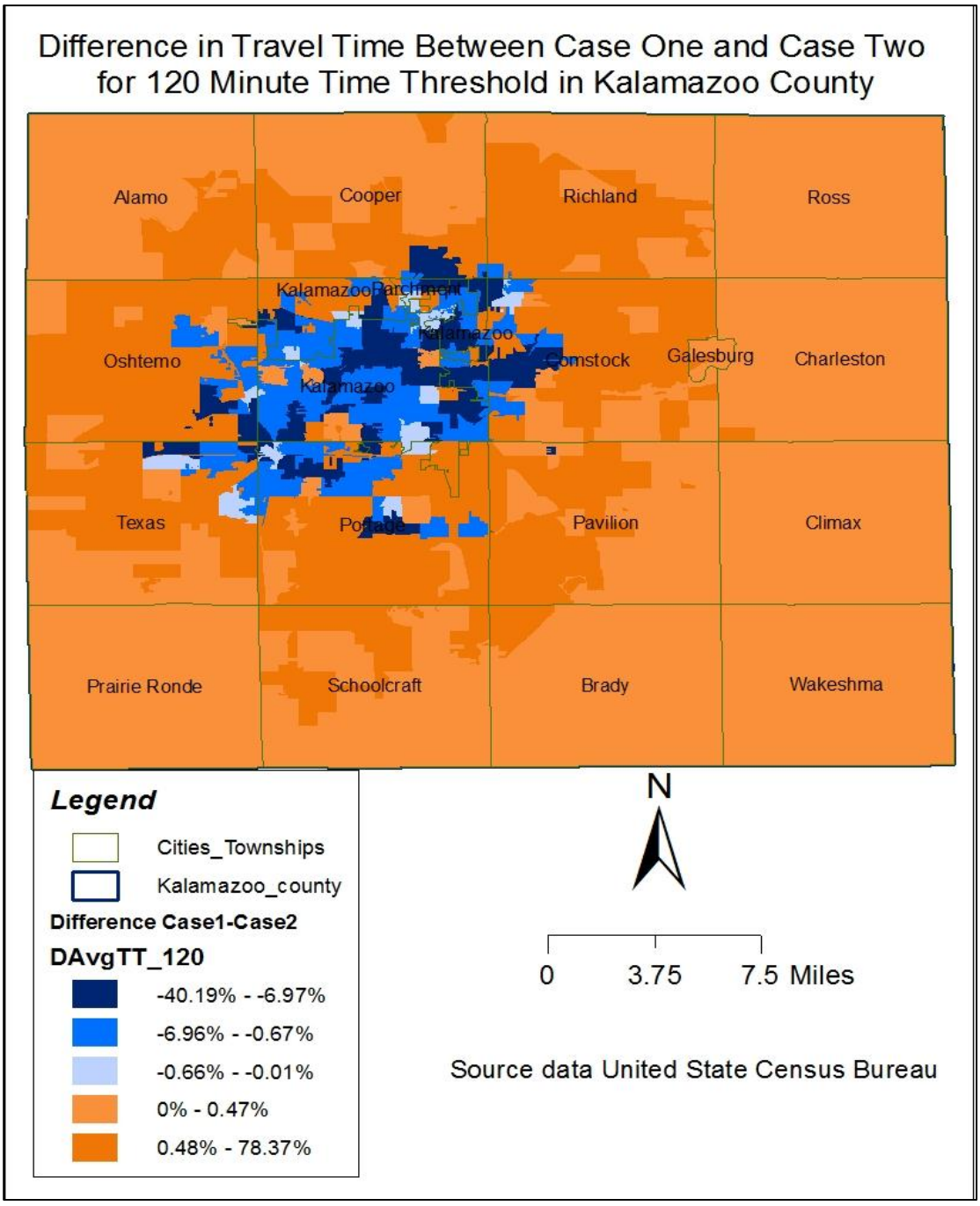
E. Difference Between Case One and Case Two in Travel Time and Walking Distance

E-1. Difference in Average Travel Time

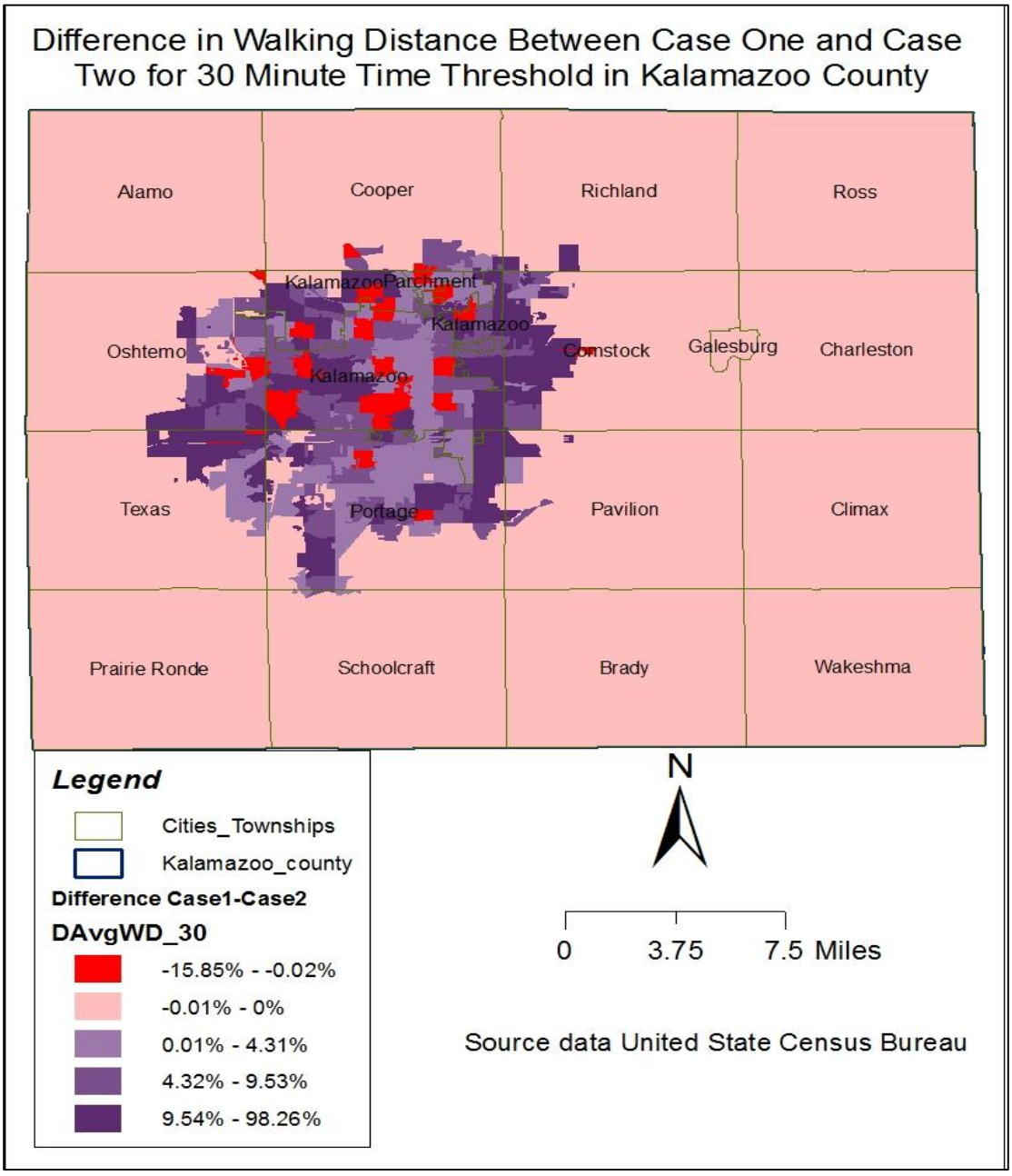


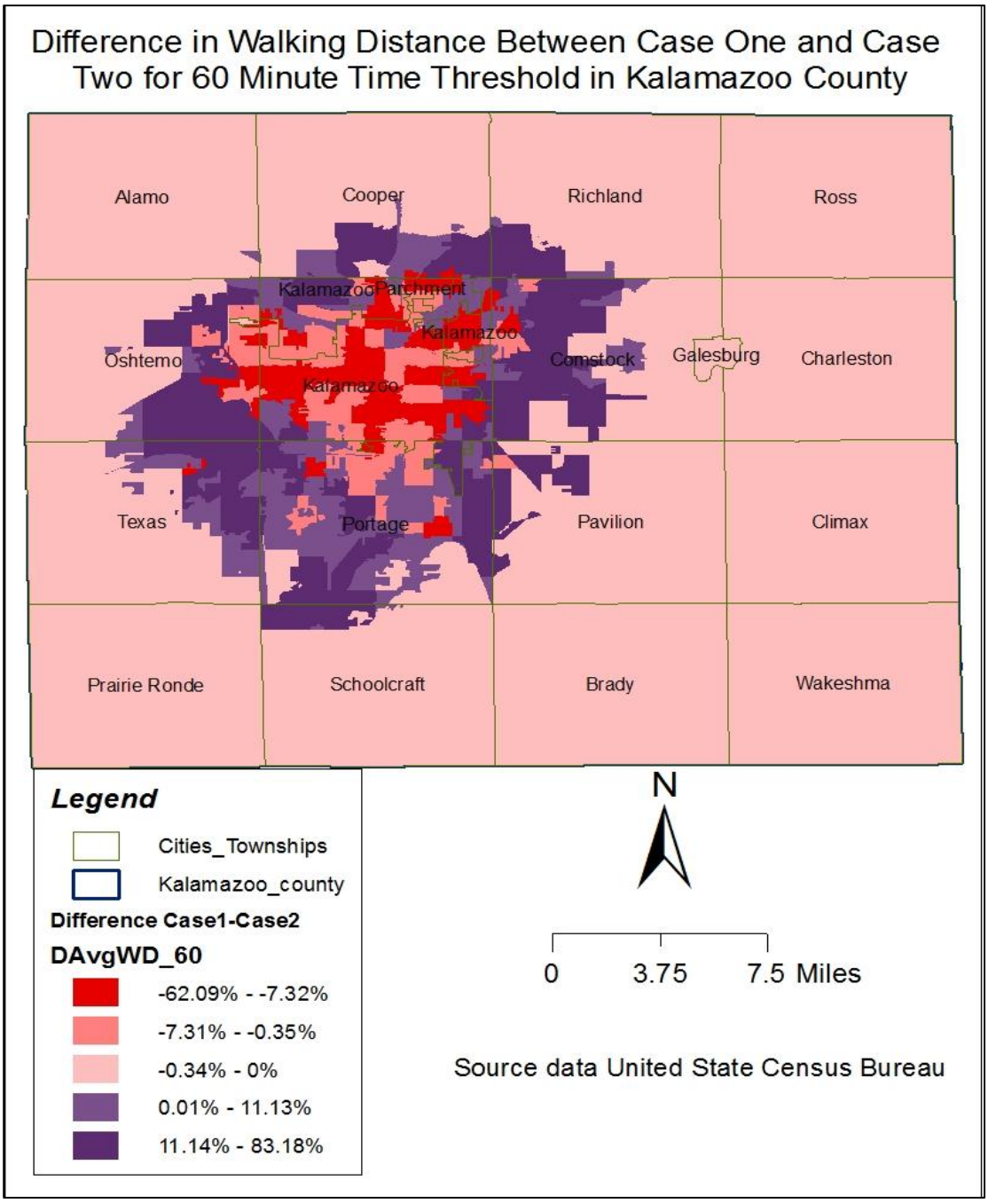

Difference in Travel Time Between Case One and Case Two for 60 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Difference Case1-Case2
DAvgTT_60
0%
0.01% - 8.4%
8.41% - 12.32%
12.33% - 24.01%
24.02% - 89.59%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

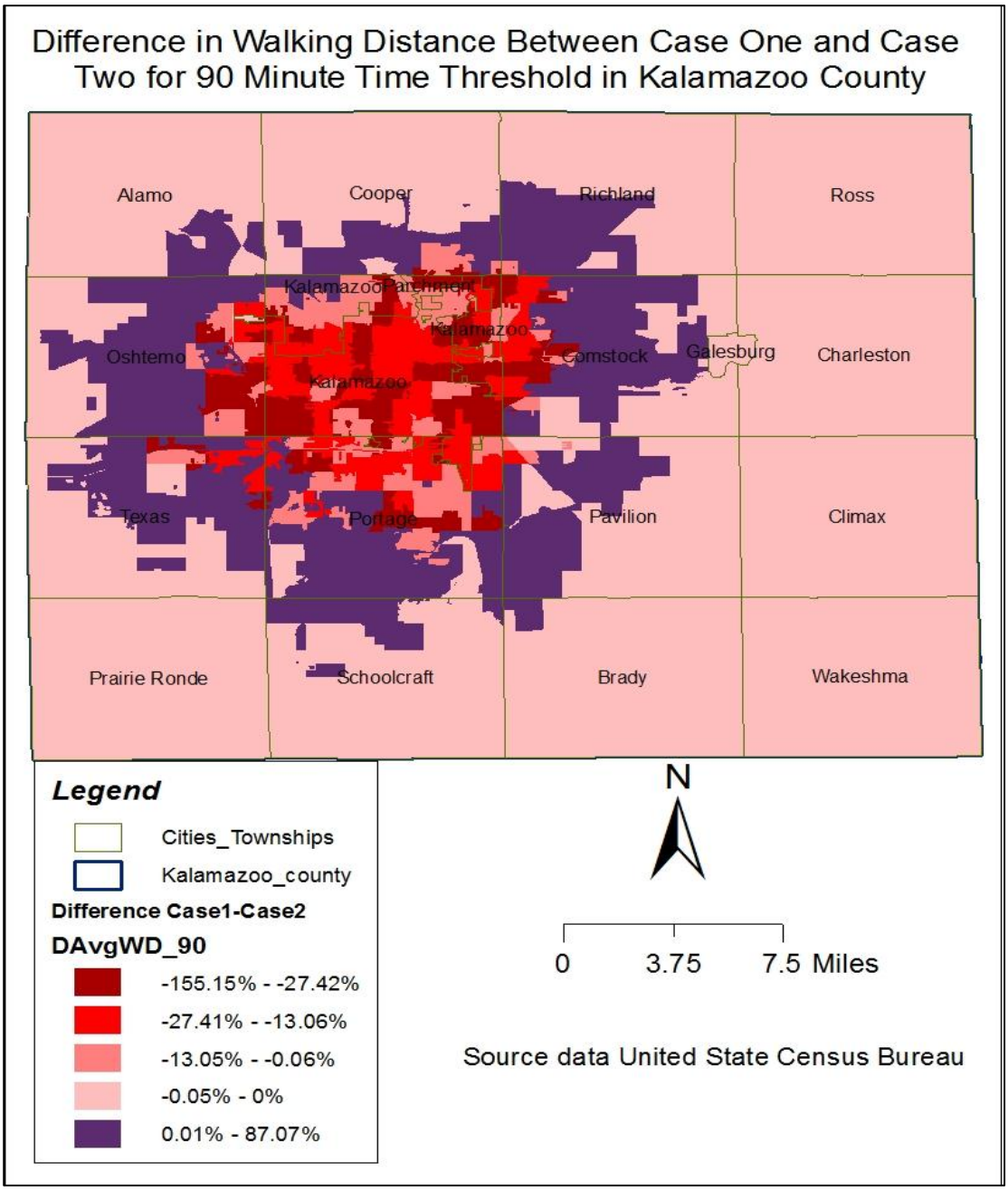

Difference in Travel Time Between Case One and Case Two for 90 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Difference Case1-Case2
DAvgTT_90
-32.05% - -0.17%
-0.16% - 0%
0.01% - 6.12%
6.13% - 15.17%
15.18% - 83.14%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

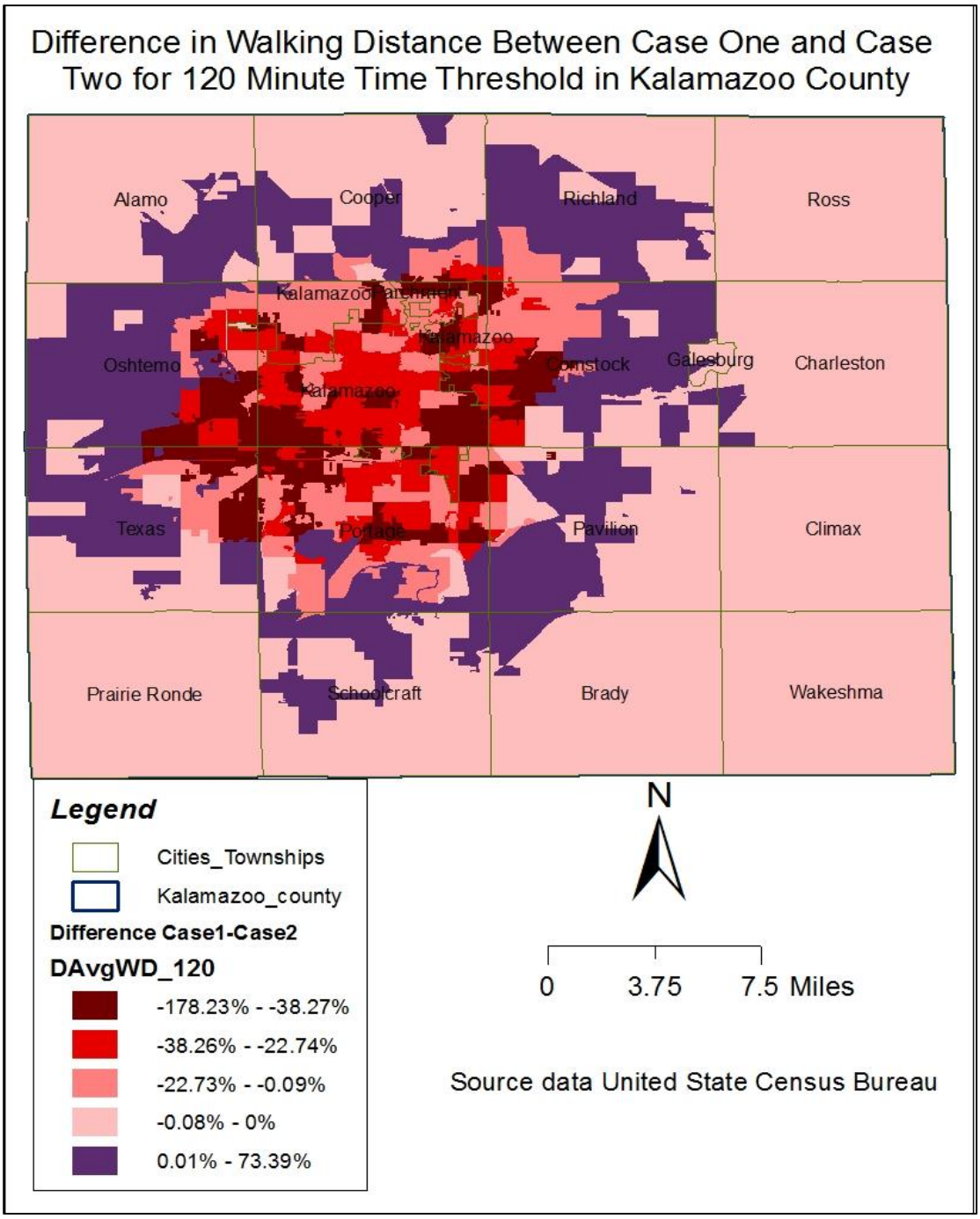

Difference in Travel Time Between Case One and Case Two for 120 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Difference Case1-Case2
DAvgTT_120
-40.19% - -6.97%
-6.96% - -0.67%
-0.66% - -0.01%
0% - 0.47%
0.48% - 78.37%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

E-2. Difference in Average Walking Distance



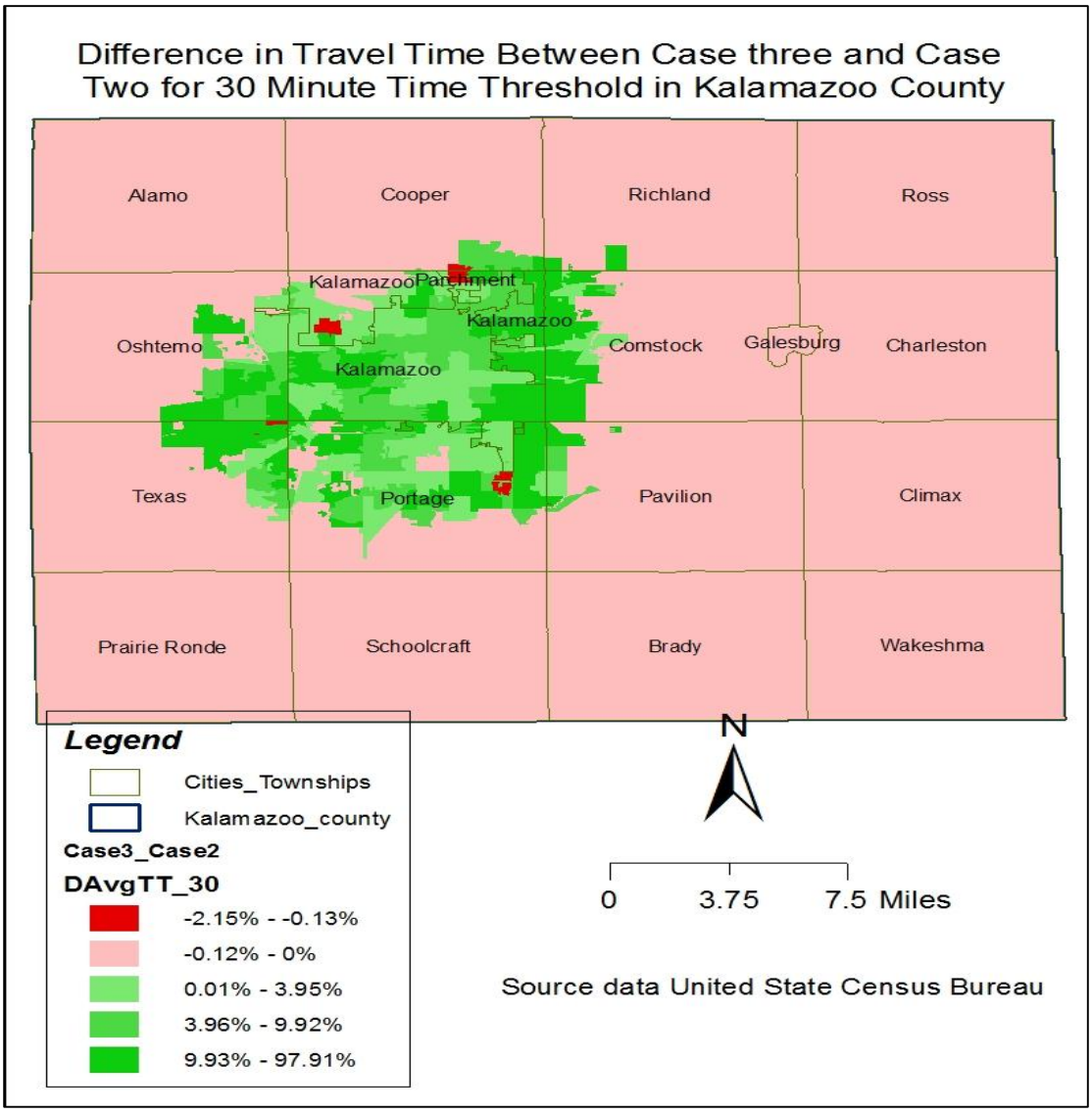

Difference in Walking Distance Between Case One and Case Two for 60 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Difference Case1-Case2
DAvgWD_60
-62.09% - -7.32%
-7.31% - -0.35%
-0.34% - 0%
0.01% - 11.13%
11.14% - 83.18%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

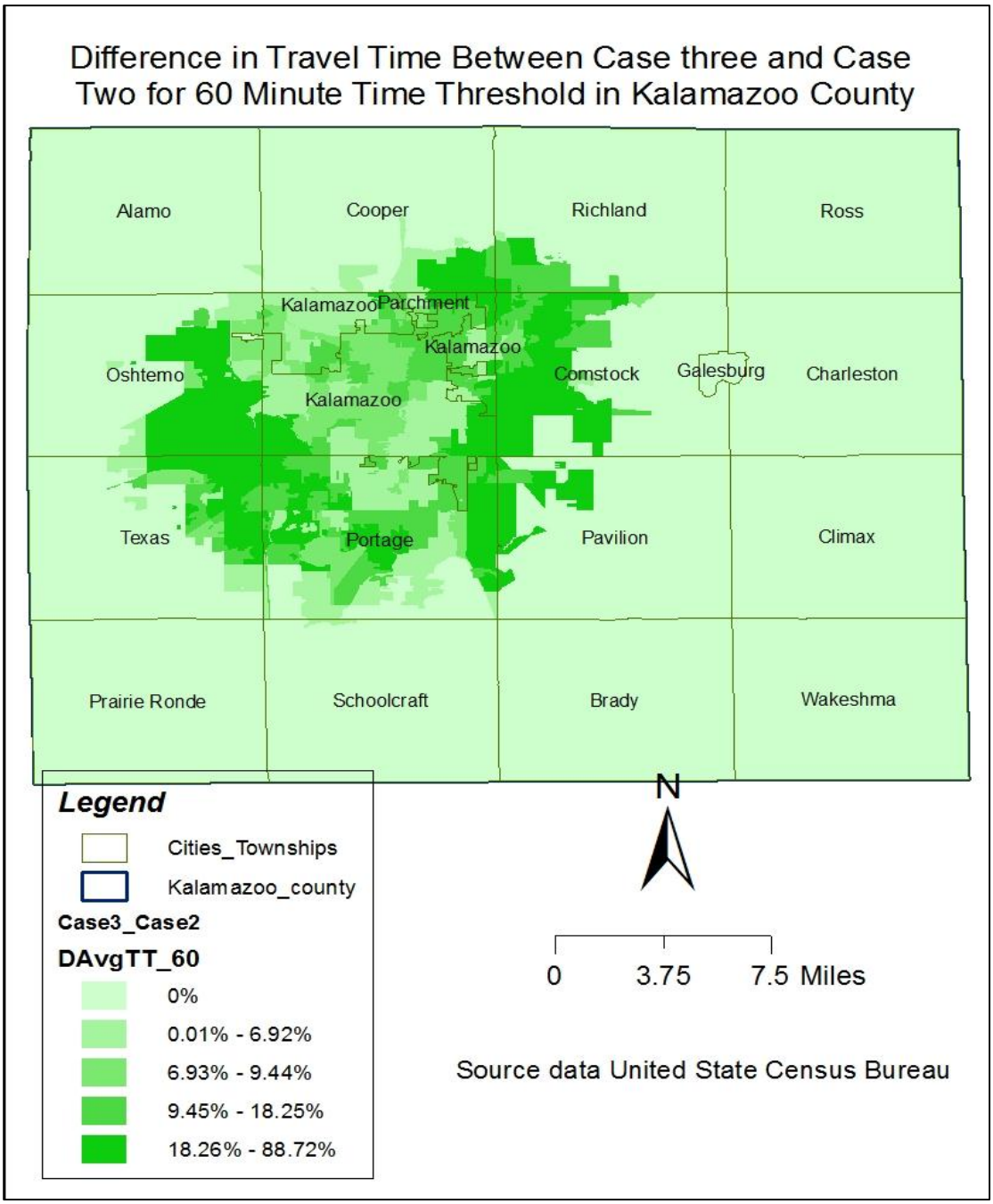

Difference in Walking Distance Between Case One and Case Two for 90 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Difference Case1-Case2
DAvgWD_90
-155.15% - -27.42%
-27.41% - -13.06%
-13.05% - -0.06%
-0.05% - 0%
0.01% - 87.07%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

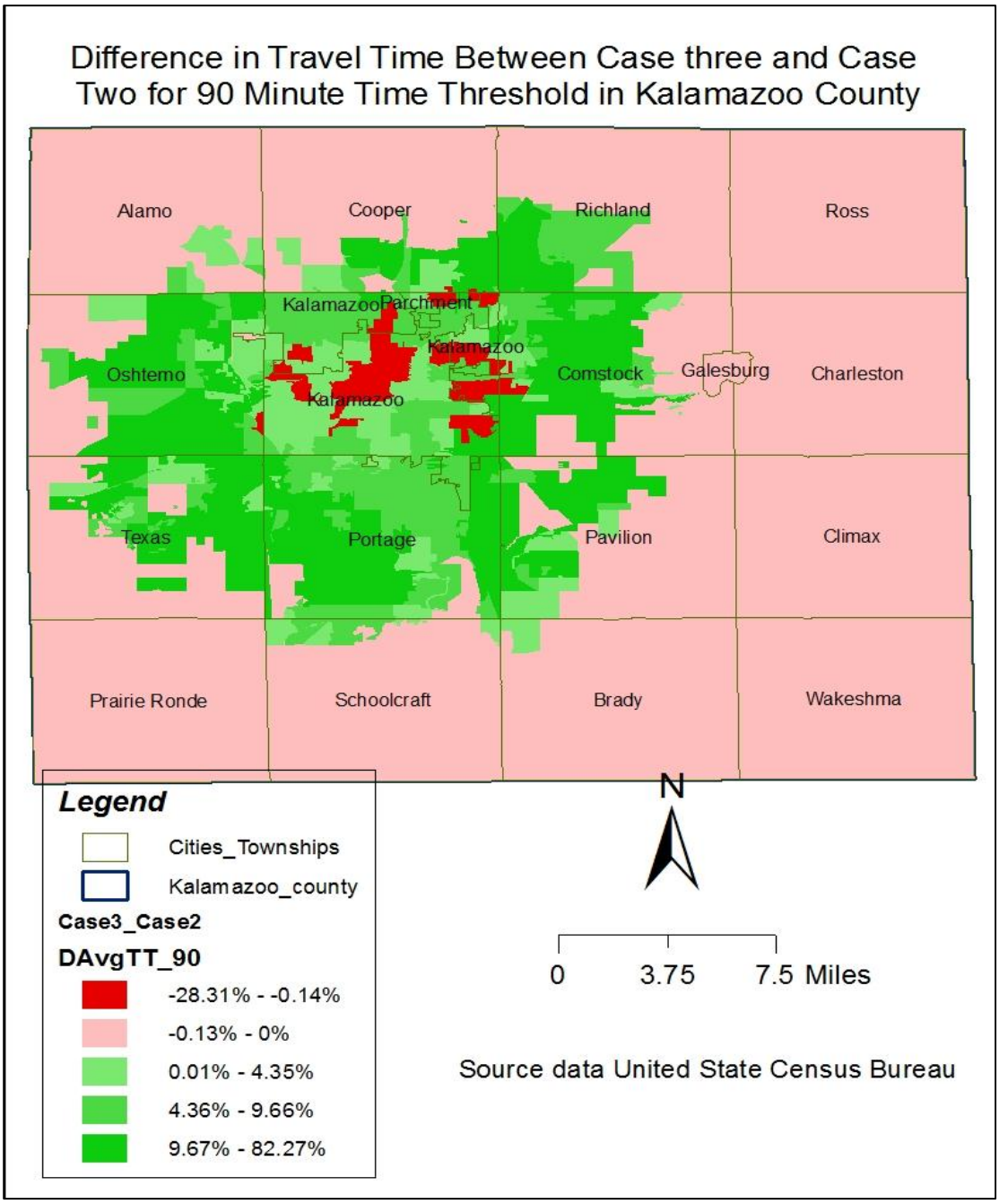

Difference in Walking Distance Between Case One and Case Two for 120 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Difference Case1-Case2
DAvgWD_120
-178.23% - -38.27%
-38.26% - -22.74%
-22.73% - -0.09%
-0.08% - 0%
0.01% - 73.39%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

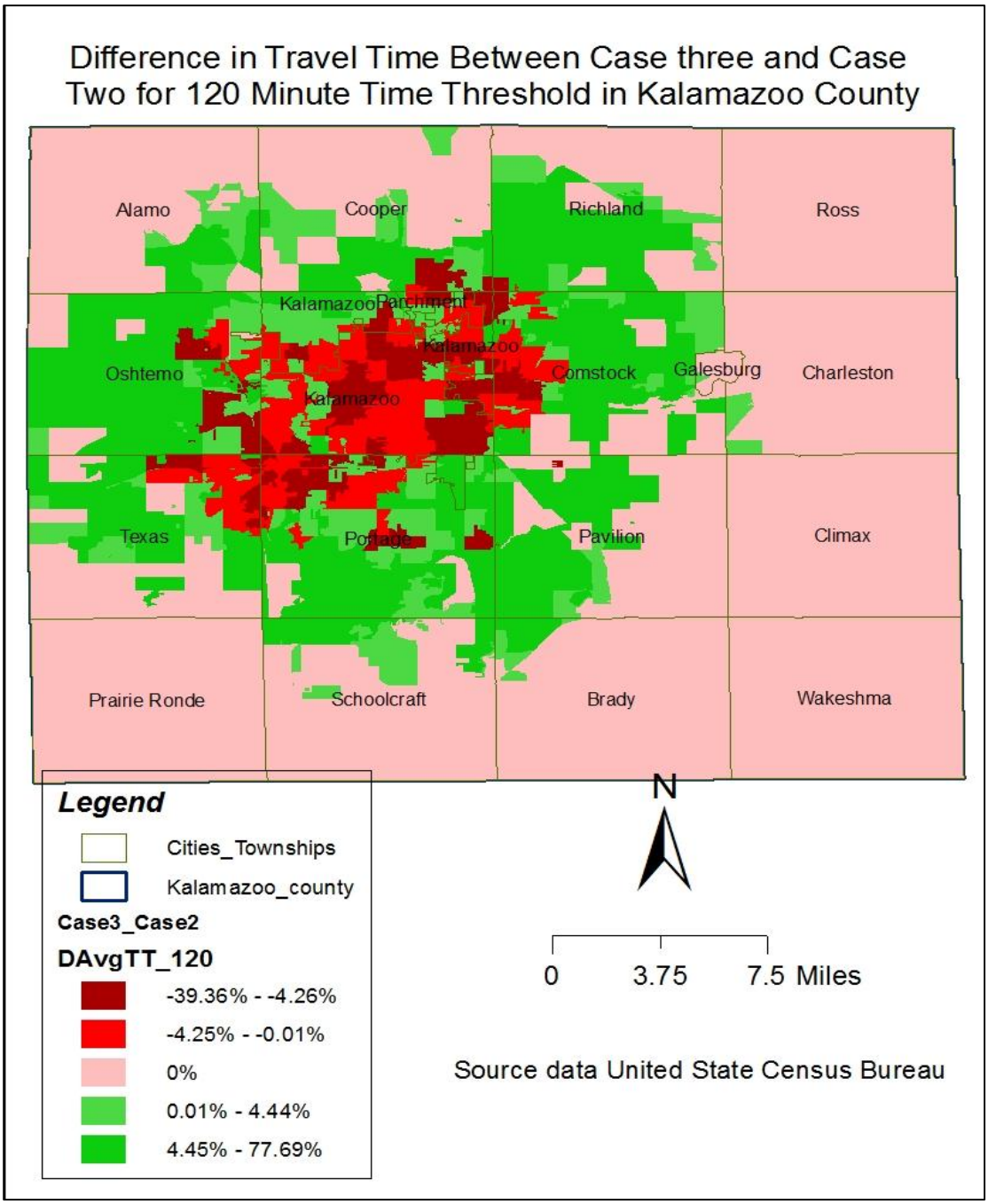
F. Difference Between Case Three and Case Two in Travel Time and Walking Distance

F-1. Difference in Average Travel Time

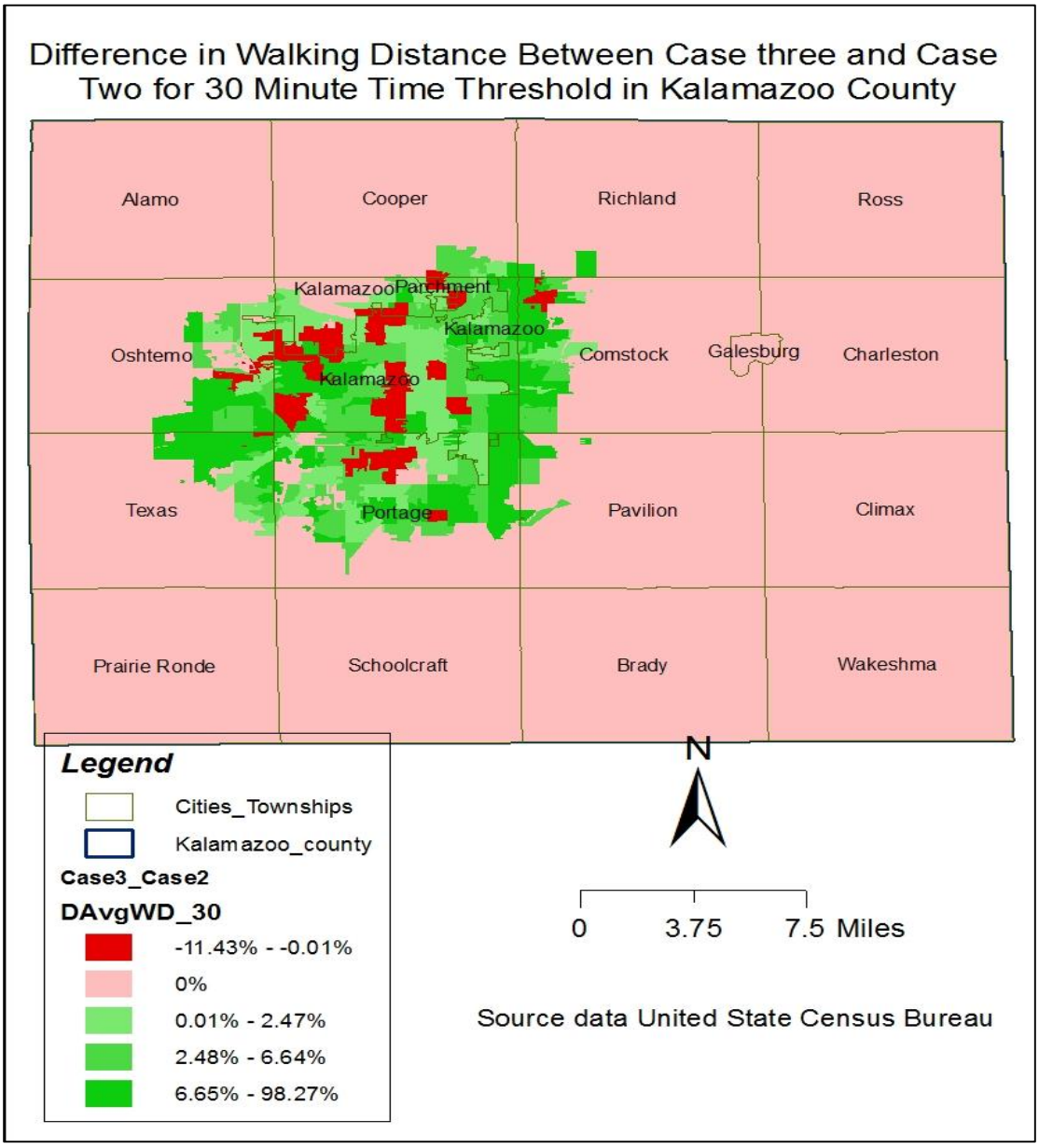


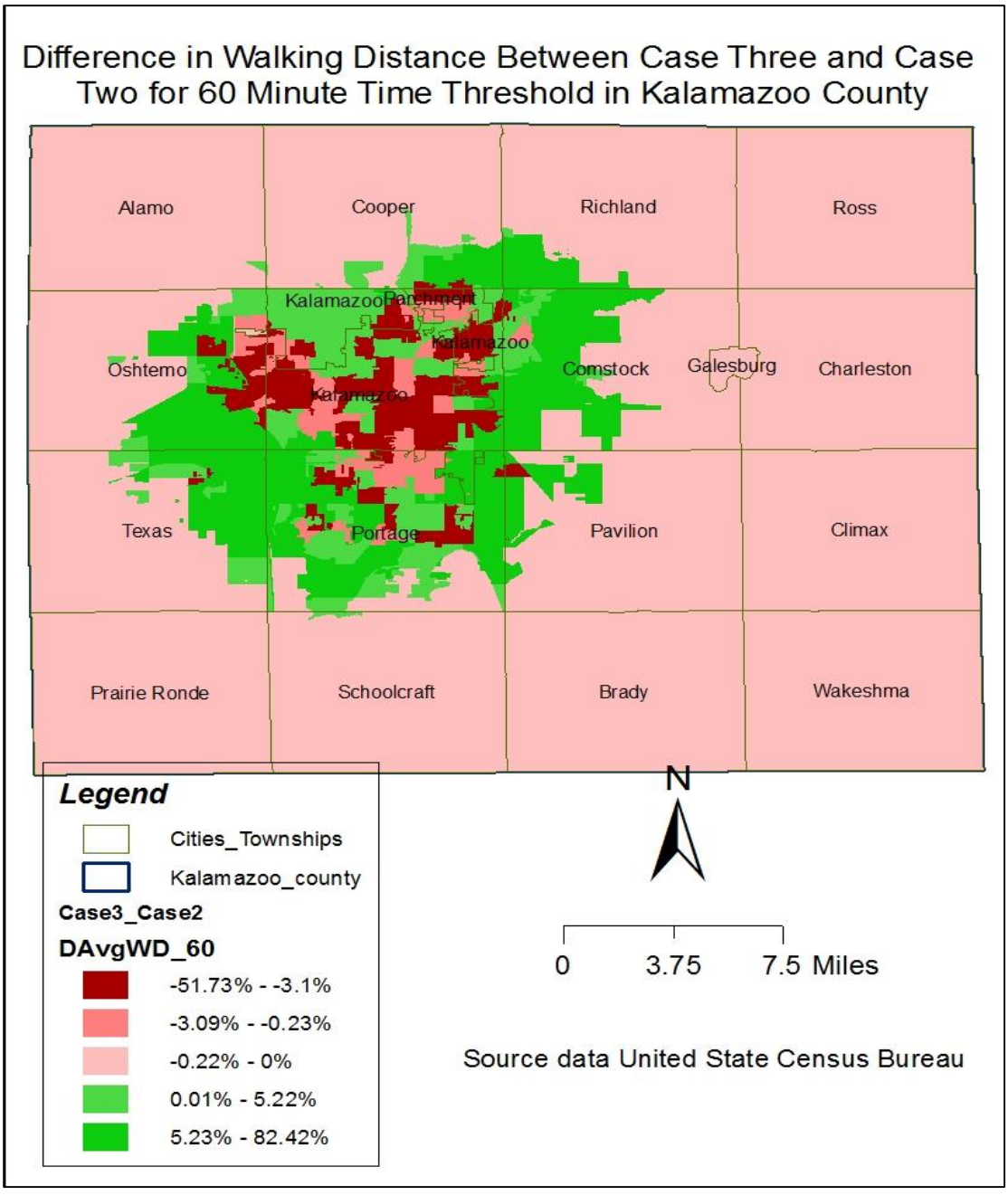

Difference in Travel Time Between Case three and Case Two for 60 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Case3_Case2
DAvgTT_60
0%
0.01% - 6.92%
6.93% - 9.44%
9.45% - 18.25%
18.26% - 88.72%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

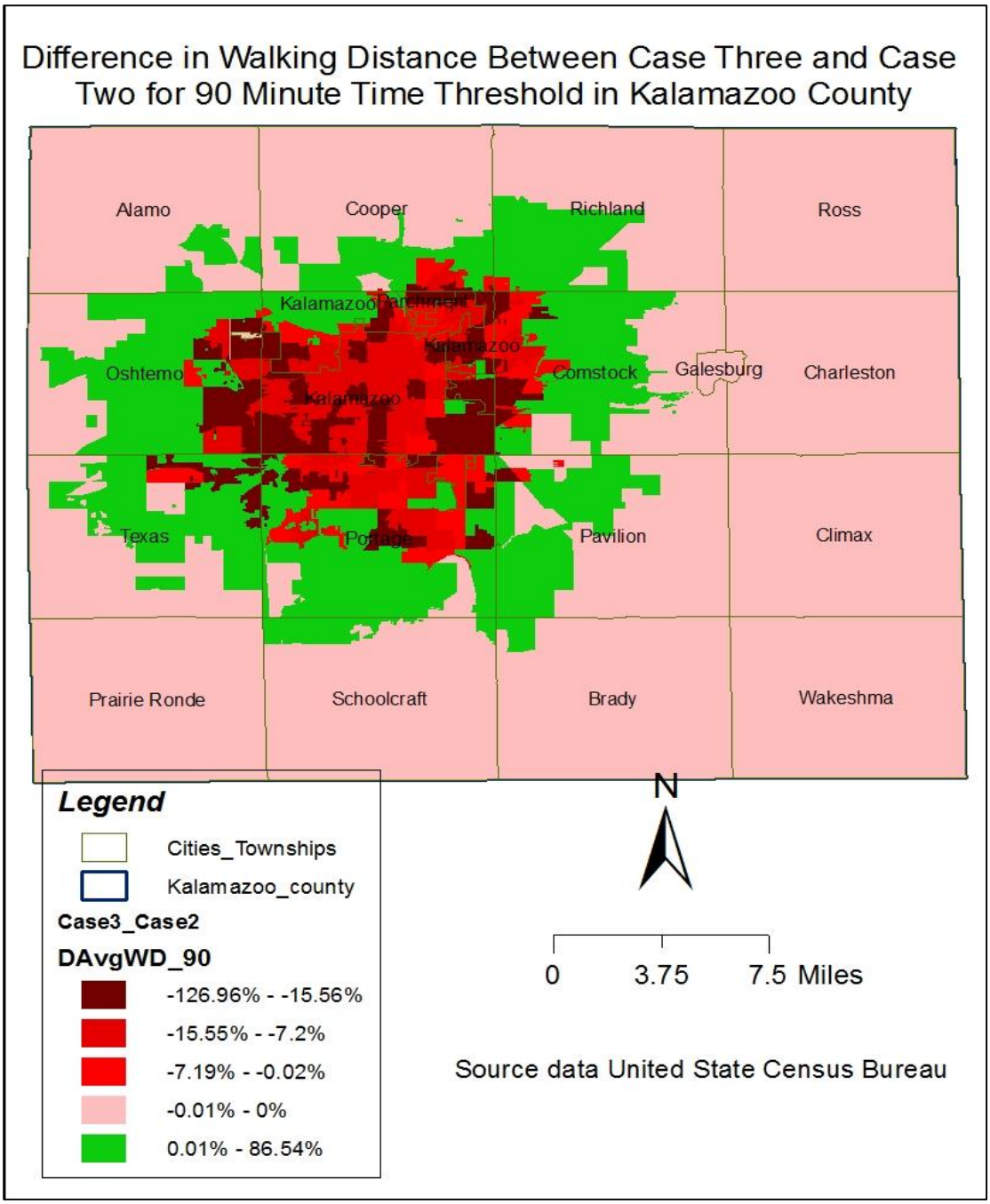

Difference in Travel Time Between Case three and Case Two for 90 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Case3_Case2
DAvgTT_90
-28.31% - -0.14%
-0.13% - 0%
0.01% - 4.35%
4.36% - 9.66%
9.67% - 82.27%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

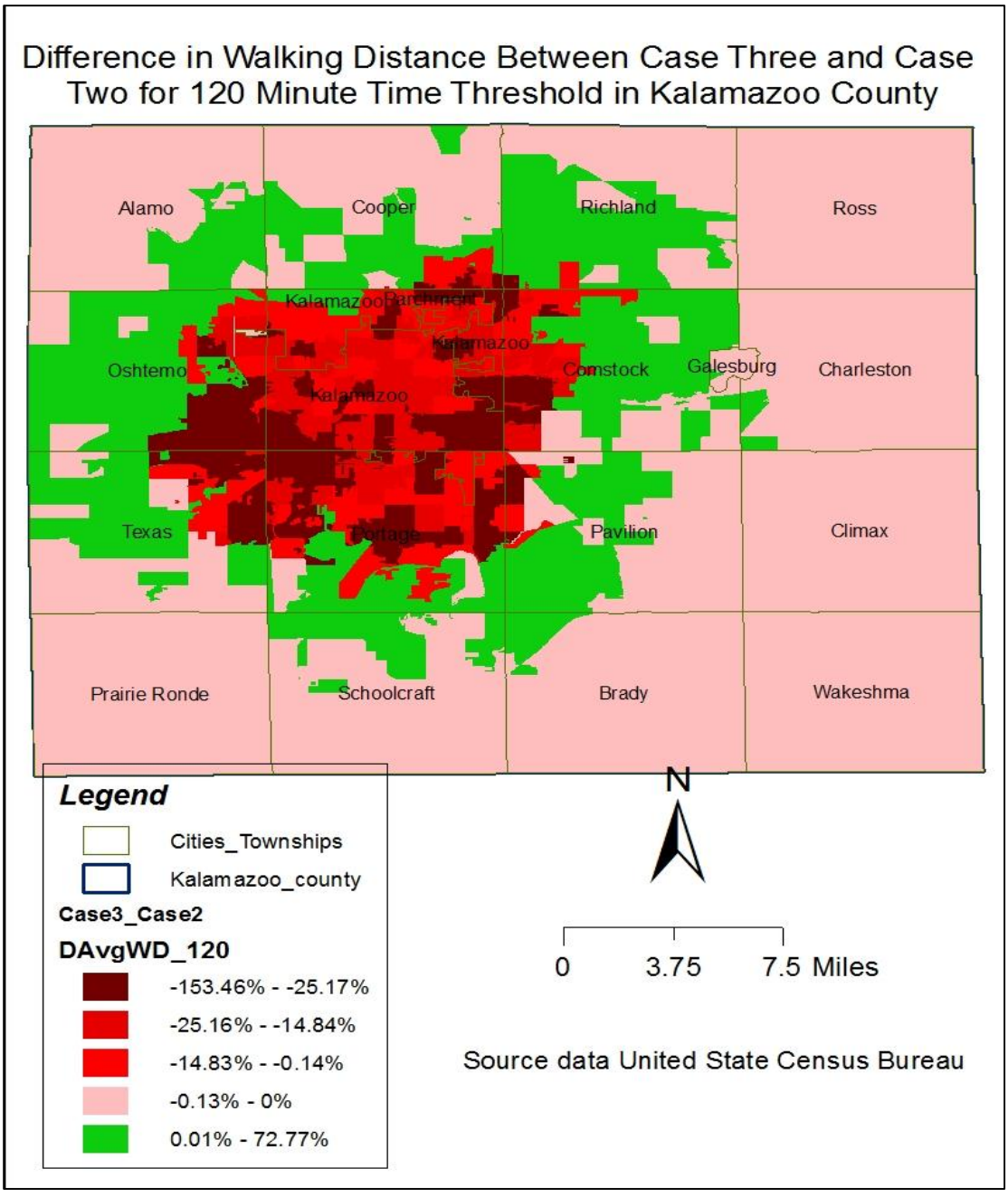

Difference in Travel Time Between Case three and Case Two for 120 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Case3_Case2
DAvgTT_120
-39.36% - -4.26%
-4.25% - -0.01%
0%
0.01% - 4.44%
4.45% - 77.69%
N
0
3.75
7.5 Miles
Source data United State Census Bureau

F-2. Difference in Average Walking Distance




Difference in Walking Distance Between Case Three and Case Two for 60 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Case3_Case2
DAvgWD_60
-51.73% - -3.1%
-3.09% - -0.23%
-0.22% - 0%
0.01% - 5.22%
5.23% - 82.42%
N
0
3.75
7.5 Miles
Source data United State Census Bureau


Difference in Walking Distance Between Case Three and Case Two for 90 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Case3_Case2
DAvgWD_90
-126.96% - -15.56%
-15.55% - -7.2%
-7.19% - -0.02%
-0.01% - 0%
0.01% - 86.54%
N
0
3.75
7.5 Miles
Source data United State Census Bureau


Difference in Walking Distance Between Case Three and Case Two for 120 Minute Time Threshold in Kalamazoo County
Alamo
Cooper
Richland
Ross
Kalamazoo
Parchment
Kalamazoo
Oshtemo
Comstock
Galesburg
Charleston
Kalamazoo
Texas
Portage
Pavilion
Climax
Prairie Ronde
Schoolcraft
Brady
Wakeshma
Legend
Cities_Townships
Kalamazoo_county
Case3_Case2
DAvgWD_120
-153.46% - -25.17%
-25.16% - -14.84%
-14.83% - -0.14%
-0.13% - 0%
0.01% - 72.77%
N
0
3.75
7.5 Miles
Source data United State Census Bureau