GIS-based spatial accessibility analysis to high schools by transit in Toledo area in 2010

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by Transit in Toledo Area in 2010

by

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An Abstract of

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Nowadays, numerous studies examine the spatial mismatch between employment and residential areas, while only a few researches investigate the spatial mismatch between public transit facilities and school locations. By applying spatial mismatch theory and distance decay effect to this thesis, I examine the spatial distribution of high schools in Toledo Area with the assistance of Average Nearest Neighbor Analysis, and test the null hypothesis that there are not enough TRATA bus stops within the quarter mile around the high schools. Finally, I conduct accessibility analysis to high schools by public transit in the study area and provide recommendations for improvement in TARTA service for schools.
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Chapter One

Introduction

1.1 Problem Statement

Nowadays, numerous studies examine the spatial mismatch between employment and residential areas, while only a few studies investigate the spatial mismatch between public transit facilities and school locations. The main purpose for this thesis is to figure out the spatial mismatch between high schools and Toledo Area Regional Transit Authority (TARTA) bus stops. It owns quite important realistic meanings since many of the students are restrained to their community schools due to poor public transit service in Toledo area, including Sylvania, Ottawa Hills and Washington Local school district. Because many of the community school students are underperforming in the Ohio Achievement Test, parents prefer to send their children to other schools even though they are far away from their homes. Unfortunately, TARTA bus stops are not easily accessible to many students due to the unreasonable walking distance from their homes. What can we do to help these children go to better schools? To achieve this goal, poor TARTA service is becoming a bottleneck, and how to improve its quality provided to the school students is the most critical problem we need to solve immediately.
Accessibility may be classified into two main categories: spatial accessibility and non-spatial accessibility. Spatial access emphasized the importance of the spatial/distance variable (Luo and Wang, 2003). On the other hand, non-spatial accessibility studies concentrate on non-geographic factors such as income, religion, ethnicity etc (Luo and Wang, 2003). In this study, I pay most attention on the walking distance at both ends of trip, which means it focuses on the distance from origins (homes) to TARTA bus stops, and from TARTA bus stops to the destinations (i.e., high school locations).

1.2 TARTA Background

TARTA, founded in 1971, carried more than 3.5 million passengers in 2010 (TARTA, 2010). In 1972, the first Park-N-Ride service (at Franklin Park Mall) was created. Ten years later, TARTA produced the downtown Loop to allow riders transfer to any other routes in 1982. Moreover, TARTA also provides services in other forms other than the most traditional bus service. In 1989, Toledo Area Regional Paratransit Service (TARPS) was created whose primary users are disabled people. Call-A-Ride was formed in 2003 which mainly focuses on the suburban area pick-up services.

Today, TARTA provides interconnected service to seven Lucas County communities – Toledo, Rossford, Ottawa Hills, Sylvania, Spencer, and Sylvania townships – along with Perrysburg, Maumee and Waterville (TARTA, 2010). In this thesis, I am concerned with the traditional TARTA bus service.
1.3 Objectives

a. Map out the locations of public high schools as well as charter and private high schools in study area using ArcGIS 10, and analyze the spatial distribution of these schools by some spatial statistics methods, such as Average Nearest Neighbor analysis.

b. To map the locations of TARTA bus stops.

c. Test the null hypothesis that there are not enough TARTA bus stops within 0.25 mile from high schools in study area.

d. Make accessibility maps.

e. Conduct a survey questionnaire about TARTA’s efficiency to high schools commuting.

f. Provide recommendations for improvement in TARTA service for schools

1.4 Study Area

In my thesis, the main study area I focus on is Toledo area in Lucas County, Ohio, including Sylvania, Ottawa Hills and Washington Local School District. In the data collection process prior to data analysis, I find out that there is only one high school in Washington Local School District, which is Whitmer High School. Whitmer High School is a public high school in Toledo, Ohio. Due to the above reason, Washington Local School District is incorporated into Toledo in this thesis for convenience, instead of listing and labeling it out alone. The map of basic profile of Toledo area within Lucas County is presented below.
Figure 1-1: Study Area

There are 103 census tracts in total in study area, Toledo has 93, and Ottawa Hill has 1, and Sylvania has 9 census tracts.
Chapter Two

Literature review

2.1 Definition of Transit Accessibility

Accessibility is a general term used to describe the degree to which a product, device, service, or environment is available to as many people as possible. Accessibility can be viewed as the "ability to access" and benefit from some system or entity (http://en.wikipedia.org/wiki/Accessibility, 2012). Some scholars point out that accessibility refers to the relative ease by which the locations of activities, such as work locations, shopping malls, and health care can be reached from a given location (Luo and Wang 2003).

Hanson presents us an all-round and concise version of definition in her book published in 2004, where she states “accessibility refers to the number of opportunities, also called ‘activity sites’ available within a certain distance or travel time” (Hanson, 2004).

A good example which could make us better understand accessibility is the Shimshal, Northern Pakistan. In 1970, it usually took locals about one whole week to nearby village on foot; however, the time villager spent reduced to 20 hours 18 years later, and in 2003 the hours people spent trimmed down to 4 hours (Cook and Butz, 2011). Apparently, in
this case this new road construction has increased the accessibility of Shimshal, Northern Pakistan to the outside world.

Transit, or mass transit, means a city-range public transportation system in which persons are carried in large numbers. Hence, public transit accessibility could be summarized as the numbers of opportunities, also called ‘activity sites’ available within a certain distance or travel time by “inter-city-connected” public transit facilities, including bus, subway, and transit stops/stations.

2.2 Spatial Mismatch Theory and US transportation

Riots that broke out in many cities in United States in 1960s had attracted attention from the US government and local communities, and then led to several commission investigations nationwide. For instance, Watts riot took place in Los Angeles in summer 1965, and it was followed by the establishment of McCome commission with a purpose to explore the root causes of this riot. The causes of these riots were traced to the high rate of African American unemployment and the poor public transit services (Gobillon, Selod and Zenou, 2007). After a couple of years of relative harmony, another disorder occurred again in 1967 characterized by at least 83 civilians were slain. After that astonishing tragedy, US President Lyndon Johnson established the National Advisory Commission on Civil Disorders and appointed Otto Kerner as the chairman (Kain, 1992). Surprisingly, the conclusions they got were very similar to McCome commission. They all agreed on the standpoint that high rate of unemployment in the African American residential areas make great contributions to this disaster; and increasing access problem
or difficulties to get to job locations, make the situation worse than it was (Kain, 1992). That is to say poor public transit services exacerbate this spatial mismatch.

The term “spatial mismatch theory” (SMH) primarily states that employment opportunities for low-income people are located far away from the areas where they live (http://en.wikipedia.org/wiki/Spatial_mismatch, 2012). It was first used by Kain in 1968 in his article housing segregation, Negro employment, and metropolitan decentralization, in which he unprecedentedly examined the relationship between racial discrimination in metropolitan housing segregation and the distribution and level of nonwhite employment (Kain, 1968). This publication argues that postwar job suburbanization accompanying with metropolitan housing market segregation make great contributions to this mismatch, and this sort of situation began to rapidly deteriorate due to the poor public transit system.

The proposal of SMH has triggered numerous studies on the spatial mismatch between job locations and residential areas distribution, and also rekindled the interest in a great deal of empirical researches related to this topic. Most of them have brought a conclusion that the disconnection of minority neighborhoods from entry-level jobs does have negative impacts on minority labor market success (Sawicki and Moody, 2000).

In 1992, Kain once again published another paper related to spatial mismatch theory, The Spatial Mismatch Hypothesis: Three Decades Later, which is most commonly considered as the sequel of the SMH he put forwarded about 30 years ago. In that article, he not only reiterates the cause of these riots, but also presented us the three solutions the Kerner Commission came up with. One of these three suggestions is creating better transportation between ghetto neighborhoods and new job locations (Kain, 1992). Sawicki and Moody point out the significant role public transit plays in people’s daily
lives. They said, aside from lack of education, training and job experience, some negative factors including suburban housing segregation, family constraint (such as child care), combined with long commuting distance and not easily accessible through public transportation jointly lead to the difficult job-seeking process (Sawicki, and Moody 2000).

Spatial mismatch has long been well known to as a large city issue (Ihlanfeledt and Sjoquist, 1998). In a paper named *Mechanisms of Spatial Mismatch* published by Gobillon, Selod and Zenou in 2007, authors suggested that there are several different factors that support the spatial mismatch phenomenon. Three factors are attributed to potential workers accessibility and initiatives. The remaining factors stress employers’ reluctance to divert away from the negative stigma of city people and in particular minorities when hiring (http://en.wikipedia.org/wiki/Spatial_mismatch, 2012).

When we examine the US transportation development history in a retrospective way, we are able to figure out that World War II could be considered as a threshold for emergence of new US transportation era. Mayer (1997) explains this division from the outlook of economics and policy. In this published paper named *Transportation Today: the U.S. Experience in a World Context*, he points out that transportation development was significantly affected by the economic condition and policy-making decisions. During World War I, the need for railroad was reduced by government funding and construction of highways locally and nationally (Meyer, 1997). After that, all things changed marked by exploring real job solutions with the advent of Great Depression in the 1930s with less emphasis on efficiency, but more on development. After that, US government shifted its concern on full employment, and this nationwide full-employment
policy kept going on for many years, and reached to another peak after the Second World War; nevertheless, transport policy became a side show, receiving little attention unless a wheel squeaked loudly (Meyer, 1997).

The article titled *The Mechanisms of Spatial Mismatch* written by Gobillon, Selod, and Zenou states that US transportation development after World War II was strongly related to the suburbanization of jobs and people from the perspective of spatial mismatch. Back in 1900s, persons preferred to locate in the densely populated central city area partly due to the high cost of transportation (Gobillon, Selod, and Zenou, 2007). The decrease in cost accompanying with the transportation development and population base increase in post-war era made people enable to move far away from Central Business District (CBD). Authors also claim that clear evidences show that the percentage of residents who lives in central city area has declined from 53% in 1970 to 42% in 2000, which is an obvious sign of steady suburbanization in the last three decades of the 20th century (Gobillon, Selod, and Zenou, 2007). It is estimated today that people live farther than nine miles away from the central city area (Glaeser and Kahn, 2001).

In turn, people moves, jobs move too. However, several social factors such as housing segregation make African American and low income residents become remoter from the job locations. Those workers who live in central city area are inhibited to commute to job locations due to the high commuting cost burden exerted on them. Apparently, poor accessibility, especially financially, discourages them to accept the jobs in the suburban areas.
2.3 Distance Decay Effect

From the above discussions on spatial mismatch theory (SMH) put forwarded by Kain in 1968, together with other following papers related to SMH researches, one could increasingly get to know that public transit system, to a great degree, plays an important role in people’s daily commuting, and I also realize that the poor public transit service might exacerbate the situation of unemployment we are faced with. For instance, job seekers might be severely discouraged by the long distance or high commuting expense exerted on them due to the poor public transit service, which could also be known as “distance decay effect”.

Information provided by Wikipedia claims distance decay effect is a geographic terminology which describes the influence of distance on two locations’ spatial interactions, and it indicates that the interaction between two locales declines as the distance between them increases (http://en.wikipedia.org/wiki/Distance_decay, 2012; Efe, 2011). Once the distance is outside of the two locales' activity space, their interactions begin to decrease (Efe, 2011). Distance decay effect could be applied to many phenomena’s illustration in our past, current and future society. When we talk about distance decay effect within the framework of human geography field, we could find out many excellent examples for its application. For instance, back in 1800s in United States, the spatial distribution of the immigrants from Europe could be well explained by distance decay effect. The majority of European immigrants decided to reside in the eastern states of the U. S. like Massachusetts, Virginia, New Jersey and New York. Westward, the number of these European settlers began to fade away by examining their accents. Apparently, in the case about European immigrants, one could claim that
farther places from their home country have lower probability of being the first choice of those immigrants’ settlement.

However, with the advent of modern transportation technology in current society, distance has less impact on our daily lives than it did in the past days. Advances in communications technology, such as phones, radio and television broadcasts, and internet, have further decreased the effects of distance (http://en.wikipedia.org/wiki/Distance_decay, 2012).

Not being restricted in the frame of geography field, distance decay effect reaches its boundary to the field of other social sciences. In an article titled distance-decay in the political geography of friends-and-neighbors voting, Gimpel et al (2008) hypothesize and test the distance-decay effect in political voting. However, the results they get indicate that distance decay effect only apply to those locations that are most regularly visited by major candidates, and the geographic range of locations from which candidates frequently appear (Gimpel et al., 2008); the impact is non-linear. Once these confines are reached, greater distances have no impact and the distance-decay effect does not apply (Gimpel et al., 2008).

An article titled the distance decay of similarity in biogeography and ecology, jointly published by Nekola and White (1999) brings us another insight into distance decay effect from the standpoint of ecology and biology. In this article, authors claim that distance decay refers to the shrink or decrease of similarity between two observations as the distance between them increases (Nekola and White, 1999). A negative relationship between distance and similarity is implicit in several ecological and evolutionary
phenomena; for instance, species turnover along an environmental gradient (Nekola and White, 1999).

Although distance decay effect also could be applied in other circumstances, such as environmental sciences (Hanley, Schlapfer and Spurgeon, 2003), examining the connection between distance and human interaction has long been recognized one of the most primary activities in geography field (Taylor, 1975; Johnston, 1973; O’Leary, 2011). In an article titled *Modeling Criminal Distance Decay*, the author, O’Leary (2011) defines distance decay as the observed fact that offenders tend to commit more crimes closer to home than farther away. Although this qualitative fact is well known, no consensus has been reached about the correct quantitative approach to distance decay (O’Leary, 2011). Correspondently, when we are talking about the distance decay effect exerted on commuting to high schools, each household prefers to choose the nearest as well as best high school for their children, and it is a common belief that the possibility of attending a school will decrease to a degree with the increase in commuting distance.

In summary, the application of distance decay effect theory has outreached for many other social science fields besides geography. In this thesis, I examine the distance decay effect in the boundary of geography transportation. The ways to measure distance are various, but the two most commonly adopted types are Euclidean distance and Manhattan distance. In this thesis, I employ Euclidean distance.
2.4 Quarter Mile Buffer

One of the most important problems in the thesis is how many miles I need to set as the walking limit. The article titled *A Transit Access Analysis of TANF Recipients in the City of Portland, Oregon* (Sanchez, 1999) mentioned 0.25 mile (about 400 meters) walking distance to the nearest public transit stop is typically regarded as the adequate public transit access. If the walking distance outnumbers this threshold, the time, cost and the inconvenience degree might cause the declined transit ridership. Likewise, five scholars from department of Civil and Environmental Engineering at Florida International University also pointed out people are willing to walk up to quarter mile to reach for the public transit facilities (Zhao et al 2003), and the farther away from the transit stop, the lower likelihood for people to take public transit vehicle. Sanchez (1999) questions the existence of ground evidence in support of the policy-makers’ continuous assertion that increased public transit mobility can positively affect employment. Given the lower number of professional research on school and transit, let alone the real evidence to prove the authenticity of the positive impact on schools exerted by better public transit. Based on my own living experience in many cities of China for more than 20 years, public transit system plays an essential or even the most important role in citizens’ daily lives, since the majority of Chinese families do not have cars due to economic as well as huge population base factors. Hence, I still hold a standpoint that the possibility of taking a bus or other transit vehicle for schools goes up under the condition of better public transit service. Similarly, Hsiao et al. (1997) employ network ratio method to prove a strongly positive relationship between bus ridership and pedestrian access.
An article talking about how to create a model for walkability calculation published in ESRI website also indicate the maximum distance one person might willing to walk. Rattan, Campese, and Eden (2012) mentioned that the walking distance criteria for grocery stores and fresh food places are all 800 meters. While, the walking distance criteria they set for the public transit stops are only 400 meters or 0.25 mile (Rattan, Campese, and Eden, 2012).

However, many of authors who focus on the accessibility research also revealed a couple of disadvantages by creating such buffers assisted by GIS technology. For example, this type of method is based on a flawed assumption that population are evenly distributed in the area, and such created buffers are Euclidian distance/ straight line distance, instead of actual walking distance etc (Zhao et al, 2003).

In this thesis, I will also employ 0.25 mile as my primary choice of buffer radius to examine the distribution of TARTA bus stops, high schools and census tracts in the study area. By the assistance of ArcGIS, I could select the accessible census tracts and high schools under the condition that they are all within the 0.25 buffer radius around the TARTA bus stops. I will also create 0.5 mile, 0.75 mile and 1 mile buffers with the assistance of ArcGIS to further examine the proximity between those activity sites and TARTA bus stops since I set a prior assumption that TARTA could not provide enough public transit service in the study area and the majority of nearest TARTA bus stops are not within the reasonable walkable distance. One mile buffer radius will be the maximum buffer I set for the spatial distribution analysis purpose.
2.5 Weighted Mean Centers (WMCs)

Having read literature on calculation of accessibility, I find out that social scientists have not reached an agreement on at what level accessibility is measured, that is to say they have not agreed on what sort of level could be the units of analysis. Traffic Analysis Zones (TAZs) are most commonly considered as a geographic unit, especially in the field of transportation analysis. TAZs selection usually varies according to the demand of the researches; some of them go to block group level like Sanchez in 1999; or census tract level such as Luo and Wang in 2003. Here, in this research I use the census tract as my unit of analysis to measure TARTA public transit accessibility. The method Sanchez (1999) employed to measure the mean walking distance is kind of similar to the way I use to calculate the distance. The mean walking distance is the outcome of measuring the straight line length between bus stops and each block group centroid, while I use WMCs of census tract as a surrogate. WMCs or weighted centroids, unlike the geographic mean center of each TAZ in which each single one of samples we pick shares the same interests of the final results, is another way to measure the arithmetic centers in which some of the samples make more contributions to the final outcomes than others. In a book titled *Quantitative Method for GIS* (Wang, 2006) explicitly illustrates the way to compute the mean distance from each physician’s address to the census tract’s centroid weighted by population number of individual block. Likewise, in my thesis I also use population WMCs, which is also known as population-weighted centroid.

Since the population is rarely distributed homogeneously or evenly within a census tract, a population-weighted centroid, instead of the geographic centroid of a census tract, would provide more accurate measurement in mean trip distances (Hwang and Rollow,
Luo and Wang (2003) point out that there might be huge distance between the geographic centroid and the population-weighted centroid, particularly in rural areas where tracts are large but persons are condensed in small space (Luo and Wang 2003). Luo and Wang 2003 also present us, specifically, the two equations that are based on the block-level demographic data to calculate the WMCs:

\[
x_c = \frac{\sum_{i=1}^{n_c} p_i x_i}{\sum_{i=1}^{n_c} p_i} \quad \text{(Equation 3-1)} \quad y_c = \frac{\sum_{i=1}^{n_c} p_i y_i}{\sum_{i=1}^{n_c} p_i} \quad \text{(Equation 3-2)}.
\]

Meanwhile, I also get a notice that authors make a systematic comparison to the pros and cons of two GIS-based accessibility measures in solving the same problem, two-step floating catchment area (FCA) method and the Gravity-Based Measure of Accessibility (GBMA) method, and both of them are implemented in the GIS environment. In my thesis, I use GBMA method or Distance-Based Measure of Accessibility (DBMA) as my main method which would be introduced in deep in the methodology part.

### 2.6 Spatial Statistical Analysis and Average Nearest Neighbor

Spatial statistical analysis methods have been broadly used in geography field in last couple of decades in 20th century. To geographers, the most well-known statistics are Moran’s I and Geary’s C (Cliff and Ord 1973; Getis and Ord 1992), and average nearest neighbor analysis are increasingly drawn more attention than it was. In an article titled *The Analysis of Spatial Association by Use of Distance Statistics*, Getis and Ord (1992) present us the usage of a family of statistics, G, to examine the spatial association and correlation. They hold the point of view that the importance of examining spatial series for spatial correlation and autocorrelation is undeniable (Getis and Ord, 1992). Authors also claim that Anselin, Griffith, and Arbia have shown that failure to take necessary
steps to account for or avoid spatial autocorrelation can lead to serious errors in model interpretation (Getis and Ord, 1992). Scholars also introduce us to G statistic applications in real world by some practical examples, such as the Sudden Infant Death Syndrome (SIDS) by County in North Carolina (Getis and Ord 1992). From the above example, one could get a general idea about how to apply spatial statistical analysis method to academic research. In this thesis, I conduct a spatial cluster analysis for high schools in the study area by the average nearest neighbor analysis method.

In recent days, spatial cluster analysis has been given a great amount of attention as an approach to examine and monitor the situation of disease (Carrel et al., 2009; Rogerson and Yamada, 2009). For instance, scholars would employ spatial cluster analysis to study the disease distribution in space, or check whether a type of carcinogen-related disease appears in a limited area of place. However, few evidences have witnessed the application of this method in the field of travel behavior (Mitra, Buliung and Faulkner, 2010). In many of previous studies or research, not only spatial cluster analysis in the global view is adopted, but also does the local view of statistical analysis. As to this thesis on public transit accessibility to the high schools in study area, the combined global and local analyses contained in average nearest neighbor could make us get familiar with the spatial distribution of high schools in the study area. In this method, significance level $\alpha$, p-value and z-score are all important for final conclusions.

The statistical terminology “test of significance” is originated by Fisher (1925) in his article *Statistical Methods for Research Workers*. The significance level is usually symbolized by $\alpha$ in the field of statistics. The significance levels that are most commonly adopted are 0.1, 0.05, and 0.01; and among all of the above significance levels, 0.05 are
most commonly chosen. Choosing level of significance is a somewhat arbitrary task, but for many applications, a level of 5% is chosen, for no better reason than that it is conventional (http://en.wikipedia.org/wiki/Statistical_significance, 2012). In the spatial cluster analysis section of my thesis, I examine whether samples are statistically significant at the level of 0.05 and 0.01 at the same time within the frame of average nearest neighbor model.

In the field of statistics, the result will be considered to be statistically significant if the null hypothesis is rejected. For instance, in the significance level testing, such as two-tail test, the null hypothesis is rejected when the p-value is less than the significance level $\alpha$, under the assumption that the null hypothesis is true. More specifically, in the following testing in Chapter Four about whether high schools cluster spatially in study area by the method of “average nearest neighbor” which are also a two-tail test featuring by “cluster or dispersed” at both ends of the curve (Figure 4-9 and Figure 4-10). ArcGIS formulates the null hypothesis that all of high schools in study area are randomly distributed in space. If the p-value is less than the significance level $\alpha$, the spatial pattern is regarded as spatially “clustered or dispersed”; when the z-score is positive, the pattern is dispersed, otherwise, it is clustered. When we look back at the principle of statistics, another statistical terminology of saying the above sort of situation is the results are considered as “statistically significant”.

I employ “average nearest neighbor analysis” in ArcGIS 10 tool as the method to evaluate the spatial distribution of high schools in the study area, since it provide us a convenient way to explore the high schools spatial distribution. From the returned values in the final output, the “Nearest Neighbor Index (NNI)” denotes the quotient of the
Observed Mean Distance (OMD) to the Expected Mean Distance (EMD), that is to say $NNI = \frac{OMD}{EMD}$. The expected distance is the average distance between neighbors in a hypothetical random distribution (ArcGIS Resource Center, 2012); if the NNI is less than 1, the distribution pattern of the high schools in the study area is categorized as clustering; if the index is more than 1, the trend is toward dispersion (ArcGIS Resource Center, 2012).

In the “average nearest neighbor analysis” tool provided by ArcGIS 10, the z-score and p-value results are all measures of statistical significance which tell you whether we should accept or reject the null hypothesis we set at the beginning (ArcGIS Resource Center, 2012). Like other cases involving null hypothesis test, I set the null hypothesis that high schools in the study area are randomly distributed, as I mentioned before, for the Average Nearest Neighbor statistical analysis.

Furthermore, the average nearest neighbor method used in this study is very sensitive to the value of area, which means small changes in the area value can give rise to a considerable change in the results, and a wrong, incorrect judgment would probably take place if we don’t take a notice of this important principle. Consequently, the Average Nearest Neighbor tool is most effective for comparing different features in a fixed study area (ArcGIS Resource Center, 2012). In the data analysis part of this thesis, one should always keep in mind that the coverage of study area has to be maintained same whenever one apply average nearest neighbor method to spatial cluster testing.
2.7 Emerging “Active Commuting to School” Idea

Although public transit services (such as bus, light rail, and metro system) has long been deemed as a better solution for a person’s transportation than private cars given the current flow of saving energy as well as mitigating traffic congestion in our planet, in recent years, there has been a trend in the field of transportation about studying the benefits of healthier ways in which students commute to schools. Scientists find that there has been a dramatic worldwide increase in the prevalence of overweight and obesity among children and adolescents nowadays (Nelson et al., 2008). Health problems such as diabetes, metabolic syndrome and hypertension are normally associated with lack of active transportation (Nelson et al., 2008).

Active school transportation, also known as “AST”, has been put forwarded for many years since the sedentary life styles and overweight children became prevalent in the developed countries. In an article titled Social-Ecological Correlates of Active Commuting to School Among High School Students, authors said students were asked the questions to: “In the last 7 days, how did you usually get to and from school” with response options of “actively” (e.g., walk, bike), “inactively” (e.g., car, bus), or “mixed”. These students were classified as actively commuting to school if they responded “actively” or “mixed” (Robertson-Wilson et al 2007). In another article related to commuting to schools, travel mode responses were also categorized as active commuting on foot or by bicycle, or inactive commuting by car, bus or train (Nelson et al., 2008). It appears that many scholars in present society are holding the standpoint that walking and bicycling are considered as healthier ways to commute to school than bus do.
At the beginning section of a paper *Spatial Clustering and the Temporal Mobility of Walking School Trips in the Greater Toronto Area, Canada*, authors jointly presented us their support to AST. They said walking and cycling for school travel may make an important contribution to overall daily energy expenditure for children and youth (Faulkner et al., 2009; Mitra, Buliung, and Faulkner, 2010). Engaging in AST, i.e., walking and bicycling may also develop into persistent environmentally sustainable travel practices through time (Black et al., 2001; Mitra, Buliung, and Faulkner, 2010), improve psychological well being (Frumkin et al., 2004; Mitra, Buliung, and Faulkner, 2010), and give rise to greater participation in physical activity later in life (Frank et al., 2003; Mitra, Buliung, and Faulkner, 2010). Policy interest in AST, as a utilitarian source of physical activity, has materialized in response to the increasing prevalence of obesity and overweight in children and youth (Frumkin et al., 2004; Mitra, Buliung, and Faulkner, 2010).

The article titled *School Location and Student Travel: Analysis of Factors Affecting Mode Choice* by Ewing, Schroer and Greene in 2004 provides us another good evidence of the increasing concern on healthier ways in which students commute to the schools. Although authors do not explicitly point out that walking or riding bicycles are healthier ways to go to school than others, they imply so. Authors state that released survey report indicated that the percentage of children (age between 5 and 15) who commute to school on foot or by bicycle has dropped to 16% in 2001, compared to about 48% in 1969. There are many reasons that could be responsible for this decline; such as poor walking environment caused by automobile development, or the school increase in size, and moving to low land price areas, all of which might eventually lead to long commuting
distance for each student (Ewing, Schroer and Greene, 2004). Besides, it is estimated that the percentage of children who live within the reasonable distance around school has gone down to 31%, compared to approximately 90% in 1969 (Ewing, Schroer and Greene, 2004). Apparently, authors argue that walking or bicycling are the best ways to commuting to school for children in spite of lack of noticeable statement in support of walking and bicycling.

In this thesis, I will not explore the benefits of the so called healthier ways to commute to high schools for students, but analyze the TARTA bus service for high schools students in the study area.
Chapter Three

Data Sources and Methodology

For this thesis, I downloaded 2010 census tract, blocks data and transportation network from U. S. Census Bureau website and ESRI, including shapefiles and demographic tables. TARTA bus stops data are provided by the TARTA general manager and TARTA official website. The source of high schools information comes from Ohio state government website. This thesis follows each of these methodologies in order shown in Figure 3-1.

Figure 3-1  Flow Chart of Methodology
3.1 Coordinate System Conversion

The first methodology I used in this thesis is projection conversion. The geographic spatial data comes from U. S. Census Bureau website http://www.census.gov/geo/www/tiger/shp.html, including census tract maps, blocks distribution, and roads networks. However, the original coordinate system I have for all these shapefiles is Geographic Coordinate System North American Datum 1983 (a.k.a. GCS NAD 1983). Moreover, the projection of high school locations shapefiles, provided by Ohio state government website, is NAD_1983_HARN_StatePlane_Ohio_North. In order to precisely calculate the WMCs for census tracts, I changed the projection of census tract and block geodata (GCS) into that of school locations. The steps to implement this procedure are listed as follows: Open Arc Toolbox → Data Management Tools → Projections and Transformations → Feature → Project. Then I dragged and dropped the census tract and block geo-data onto Input Dataset field, and set the “NAD_1983_HARN_StatePlane_Ohio_North” as the choice of the output coordinate system.

Changing different coordinate systems into a same one is a very important step for all of the following processes. For example, in the process of figuring out the WMCs for all census tracts, I need to input all of points’ X-Y coordinates at block level.

3.2 Study Area Boundary Confirmation

The second task one needs to do after having converted all kinds of projections into the same one is to figure out the borderline of the study area. The downloaded shapefiles from U. S. Census Bureau only provide us geo-data at the level of Lucas County, instead
of Toledo area. There are 128 census tracts and 8911 blocks in Lucas County. Lucas County census tract shapefile was jointed with Toledo blocks’ demographic tables based on the same field “TractID” keeping only the matching records. This leaves us with 93 census tracts and 5570 blocks in Toledo city. In addition, there are 1 census tract in Ottawa Hills and 9 census tracts in Sylvania area (partly). To summarize, there are 103 census tracts in the boundary of the study area.

3.3 Geo-coding High Schools in Study Area

This section discusses the procedure to create a complete, geo-coded shapefile of all the high schools in the study area with the attributes like high school name, address, city, state, zip code, type of high schools (public, charter and private), and their X-Y coordinates. The “Editor” toolbox in ArcGIS 10 plays an essential role in this section. In the first step, confirmation of each high school’s exact location on the earth should be given the highest priority. With the assistance of Google Earth, I could easily record the exact location for each high school. Then I added X-Y coordinates by entering their latitudes and longitudes in the format of Degrees Minutes Seconds (DMS) in the “Editor”. Upon completion of data entry, I also needed to convert the coordinate system (WGS 1984) of high schools into the previous one, which is “NAD_1983_HARN_StatePlane_Ohio_North”. Finally, I added other useful text information by “Editor” toolbox. All these steps left with 38 high schools in total in the study area as shown by Figure 3-2 and Figure 3-3.
Figure 3-2: Public High Schools in Study Area
3.4 Null Hypothesis

The null hypothesis of this research states that there are not enough TARTA bus stops within 0.25 mile from high schools in the study area. As to the regular procedure, I should randomly select out a group of bus stop points, for example 50 or 100 bus stops, as testing samples since there are 2108 bus stops in total, and then I also assume a percentage, for instance 20%, as the extent to which TARTA bus stops are within the distance of 0.25 mile. Hence, I could propose the following hypothesis: there are less than 20% TARTA bus stops that are within the distance of 0.25 mile.
However, with the assistance of computer technology in recent days, I could easily and directly reach the level of the entire population analysis, instead of working with samples. For example, ArcGIS 10 provides us a convenient way to fulfill this goal by creating a distance table for all of 2108 bus stop points as well as 38 high schools (2108*38=80104 selections in the distance table created) and attribute selection under the restraint of “less than or equals to quarter mile”. Another alternative I could also use is “select by location” provided by ArcGIS 10, to find out the bus stops that are within the distance of 0.25 mile around high schools.

3.5 Weighted Mean Centers (WMCs)

This study aims to figure out the public transit accessibility of each census tract to high schools since it is hard to calculate the accessibility score at the level of individual household because of lack of data. Weighted Mean Centers (WMCs) or weighted centroids, which is different from geographic mean center in which each sample picked plays an equal role to the final result, is another way to calculate the arithmetic center in which some of the samples make more contributions to the final outcome than others. In social science, we often map out the WMCs based on sales, incomes, populations and so on. In this thesis, I adopt populations of decennial census data. The equations to calculate the WMCs are listed below (Luo and Wang 2003):

\[ X = \frac{\sum_{i=1}^{n} P_i X_i}{\sum_{i=1}^{n} P_i} \]  
\[ Y = \frac{\sum_{i=1}^{n} P_i Y_i}{\sum_{i=1}^{n} P_i} \]  
(Equation 3-1)  
(Equation 3-2)
Where, $X_i$ and $Y_i$ represent the (x, y) coordinates of each block’s geographic mean center, 
$P_i$ is the block population, and X and Y denote the coordinates of WMCs, or population-weighted centroid.

As to specific GIS operation, Arc Toolbox provides us a useful kit to solve this problem. Following is the technique that was used in this research: Open Arc Toolbox → Spatial Statistics Tools → Measuring Geographic Distributions → Mean Center, drag and drop the blocks shapefile as the input dataset, and set the population of each block as weight field, and TractID as case field respectively.

3.6 GBMA and DBMA

Several social scientists (Hanson, 1995; Thompson, Brown, and Bhattacharya, 2010) have begun to adopt a modified version of Gravitation Law in their research on transportation accessibility in recent years that is known as Gravity-Based Measure of Accessibility (GBMA). From the perspective of accessibility analysis, we often use the following simple equation:

$$A_i = \sum_{j=1}^{n} \frac{O_j}{R_{ij}^\beta} \quad \text{(Equation 3-3)}$$

Where, $A_i$ denotes the accessibility of each census tract WMCs to the high school locations, $O_j$ means the number of high schools, $R_{ij}$ represents the existing resistance factors like distance, time or cost between WMCs of census tracts and high school locations, and $\beta$ is traffic-friction coefficient.

In Equation 3-3, opportunity is a quite important parameter. In the most traditional accessibility analysis, such as job-housing accessibility problem, we often need to figure out the number of job openings in Traffic Analysis Zones (TAZs) and take it as the
opportunity. Furthermore, if we are for instance, dealing with the spatial accessibility to primary health care, more physicians indicates more opportunity for the patients. Unlike the primary health care problems I mentioned, the opportunity each high school supplies does not make much contribution because in this thesis whether reasonable walking distance exists at both ends of trips (i.e. from home to bus stops as well as from bus stops to high school locations) is much more important. Therefore, I set the value of opportunity as a constant in this research. For easy calculation, I assume that the opportunity equals to 1. As it refers to the traffic friction coefficient, I set \( \beta \) equal to 2 since many social scientists (Sanches, 1999; Thompson, Brown, and Bhattacharya, 2010) adopted 2 as the coefficient when they dealt with the accessibility problems. Therefore, in the following steps of this part, the GBMA model adopted could be simplified as follows:

\[
A_i = \sum_{j=1}^{n} \frac{1}{d_{ij}} \quad \text{(Equation 3-4)}
\]

Equation 3-4 could be viewed as a simple version of GBMA or could be considered as Distance-Based Measure of Accessibility (DBMA) to some extent. DBMA involves only the distance to and from an origin and destination of a trip or a transit station. Many transit planners, for instance, use a 0.25 mile buffer around a transit stop. They designate locations that lie within the buffers as having access to public transit facilities, and those outside as lacking transit access (Sanchez, 1999; Sawicki and Moody, 2000).

Since the straight line distance from west part of Toledo to east part is around 12 miles, I decided to create buffers with a radius of 5 miles as the on-road distance using following technique: Open Arc Toolbox → Analysis Tools → Proximity → Point distance. In this way, a table named “Dist.dbf” was created with a field of distance from each high school location to WMCs of each census tract. This left us with 3914 records.
(103 census tracts × 38 high schools). I further selected those records under the condition of “distance is less than or equals to 5 miles”, which helped us know all of WMCs for each census tract around every high school with a radius of 5 miles. Eventually, I exported the selected records to a new table name “Dist_5miles.dbf”.

Typically, when social scientists manage accessibility questions, they analyze the data at the TAZs level at both origins and destinations, especially for job-housing accessibility problems. When it refers to distance between house and job locations, it often goes to the distance of TAZs’ mean center. The reason for this is that there are many job opportunities in one zone, and it is unrealistic to measure the distance from house to each job locations. In this thesis, however, there are 38 high schools in study area, and there is possibility that there are census tracts with no opportunities at all (for instance, Sylvania area and the east part of Toledo). Certainly, there are some census tracts characterized by multiple education opportunities, such as downtown of Toledo. Therefore, the limited number of high schools in study area makes it possible to calculate the distance for each high school separately.

3.7 Database Technique

While joining two tables together based on a common field like Census Tract ID or the Block ID, some of data from the U. S. Census Bureau were either presented in the form of “Census Tract 0002, Lucas County, Ohio”, or “US390950067002005”; but the only useful information for this study was “0002” or “2005”. Therefore, the first question is how to extract “0002” as well as “2005” from this complicated string. The most
A convenient way that I can come up with is Mid Function in Excel environment, i.e. Mid (text, start_num, length).

Unfortunately, some of the data are not as regular as the above ones whose starting positions for each useful string are all 14. What do I do if the starting number and length of characters are also variables? How can I extract the first name and last name from “Johnson, Eric”, or what can I do if I want to extract the street names from a redundant list? In Microsoft Excel sheet, I notice that the FIND as well as LEN function can facilitate me to figure out the length of useful character, such as LEFT (A3, FIND ("", A3)-2), or RIGHT (A3, LEN (A3)-FIND ("", A3)-1).

In the final step of calculating total accessibility of WMCs at the level of census tract, I need to sort out the records with the same INPUT_FID and sum them up. What is noticeable is that in the process of creating point distance table by ArcGIS, two new fields are made to identify the WMCs (INPUT_FID) and high school locations (NEAR_FID). When I open the table “Dist_5miles.dbf”, I could take use of SUMIF function provided by Excel spreadsheet to achieve this goal. However, I have to enter this function more than 100 times since the selections I have in this table are as many as 1800. The huge volume of selections in the created distance table makes me unable to process the data one by one. The alternative plan I come up with is the Visual Basic Programming in the Excel macro file, which make me reach the goal to the same degree but with much less efforts.

The following section is a macro program I wrote by using Visual Basic to calculate total accessibility, which could be run in the environment of Excel spreadsheet 2007. For example, 81 accessible WMCs within 1/4-mile buffer around TARTA bus stops are
automatically valued from 0 to 80 by computer, and then this Visual Basic program helps me to sum up the accessibility with the same INPUT_FID.

Sub custom_accessibility()

Dim i, j, accessibility
Cells (1, 6) = "INPUT_FID" 'cells (row, column) = value
Cells (1, 7) = " accessibility "
For j = 0 To 80 'loop through INPUT_FID from 0 to 80
  accessibility = 0
  For i = 2 To 1824 'loop through cells A2 to A1824 to check for INPUT_FID
    If (Cells (i, 1) = j) Then 'they match, sum them up
      accessibility = accessibility + Cells (i, 5)
    End If
  Next i
  Cells (j + 2, 6) = j 'output the results
  Cells (j + 2, 7) = accessibility
  Next j

End Sub
Chapter Four

Results and Discussions

4.1 Quarter Mile Buffers Around High Schools

The reason why I perform the 1/4-mile radius buffer is that quarter mile is the typical distance that a person would like to walk to catch up the public transit, such as bus (Sanchez, 1999; Alam, 2005; Alam 2009; Thompson, Brown and Bhattacharya, 2010). There are 2108 bus stops, and 38 high schools in study area. However, the 1/4-mile buffer map shows that there are only 186 out of 2108 bus stops within the distance of quarter mile around the high schools, which means the percentage of TARTA bus stops within 0.25 miles of destinations (high schools) is as low as 8.8% (Table 4.1). When I increase the buffering radius up to 1 mile, there are a total of 1514 (Table 4.1) bus stops in that area. As to the results of testing the null hypothesis “H₀: there are less than 20% of TARTA bus stops within the distance of 0.25 mile”, apparently, we do not reject the hypothesis since 8.8% is much less than 20%.

<table>
<thead>
<tr>
<th>Buffer radius</th>
<th>0.25 mile</th>
<th>0.5 mile</th>
<th>0.75 mile</th>
<th>1 mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bus stops</td>
<td>186/2108</td>
<td>619/2108</td>
<td>1106/2108</td>
<td>1514/2108</td>
</tr>
<tr>
<td>Percentage of bus stops</td>
<td>8.8%</td>
<td>29.3%</td>
<td>52.5%</td>
<td>71.8%</td>
</tr>
</tbody>
</table>
From Table 4.1, I find that when I increase buffer radius to 0.5 mile, the percentage of TARTA bus stops within created buffer is as low as 29.3%, and even when I raise my buffer threshold up to three times as the most typical walking distance of 0.25 mile, the percentage just stays about 50%. Only when the walking distance goes up to an unreasonable high level of “one mile” does percentage of bus stops step up to 71.8%. Although walking speeds can vary greatly depending on factors such as height, weight, age, terrain, surface, load, culture, effort, and fitness, the average human walking speed is about 3 miles per hour (mph) or 4.4 feet/second (http://en.wikipedia.org/wiki/Walking, 2012). It is estimated that a human being has to spend as many as 20 minutes to finish 1 mile walking for arriving at the nearest TARTA bus stops around their high schools. However, one mile walking distance could not be accepted by most of school commuters by its estimated 20 minutes walking time. From quarter-mile buffers to one-mile buffers around high school locations are presented in the following eight maps: Figure 4-1 to Figure 4-8.
Figure 4-1: 1/4-Mile Buffers Around Public High Schools
Figure 4-2: 1/2-Mile Buffers Around Public High Schools
Figure 4-3: 3/4-Mile Buffers Around Public High Schools
Figure 4-4: 1-Mile Buffers Around Public High Schools
Figure 4-5: 1/4-Mile Buffers Around Charter and Private High Schools
Figure 4-6: 1/2-Mile Buffers Around Charter and Private High Schools
Figure 4-7: 3/4-Mile Buffers Around Charter and Private High Schools
There are totally eight public high schools in Toledo Public Schools (TPS) district, one public high school in Ottawa Hills, two public high schools in Sylvania, and one public high school in Washington Local School District. The numbers of TARTA bus stops within these public schools’ buffer are listed in Table 4.2. It tells us that Sylvania Southview High School does not have any bus stops within its 1/4-mile and 0.5-mile buffers; while the Scott High School in TPS school district has the highest number of bus stops than others. What is noticeable is both Ottawa Hills High School and Sylvania Northview High School do not have any bus stops within their 1/4-mile buffers.
Table 4.2: Number of Bus Stops within High School Buffer

<table>
<thead>
<tr>
<th>School District</th>
<th>School Name</th>
<th>0.25 mile</th>
<th>0.5 mile</th>
<th>0.75 mile</th>
<th>1 mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toledo Public Schools (TPS)</td>
<td>Bowsher High School</td>
<td>3</td>
<td>22</td>
<td>38</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Rogers High School</td>
<td>3</td>
<td>6</td>
<td>16</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Scott High School</td>
<td>14</td>
<td>47</td>
<td>92</td>
<td>155</td>
</tr>
<tr>
<td></td>
<td>Start High School</td>
<td>6</td>
<td>29</td>
<td>92</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Toledo Early College High School</td>
<td>8</td>
<td>22</td>
<td>45</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Toledo Technology Academy</td>
<td>7</td>
<td>27</td>
<td>69</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>Waite High School</td>
<td>7</td>
<td>32</td>
<td>49</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>Woodward High School</td>
<td>12</td>
<td>32</td>
<td>75</td>
<td>106</td>
</tr>
<tr>
<td>Ottawa Hills</td>
<td>Ottawa Hills High School</td>
<td>0</td>
<td>7</td>
<td>34</td>
<td>58</td>
</tr>
<tr>
<td>Sylvania Public</td>
<td>Northview High School</td>
<td>0</td>
<td>10</td>
<td>24</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Southview High School</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Washington Local</td>
<td>Whitmer High School</td>
<td>3</td>
<td>24</td>
<td>49</td>
<td>78</td>
</tr>
<tr>
<td>Charter and Private Schools in Study Area</td>
<td>Toledo School for the Arts</td>
<td>14</td>
<td>36</td>
<td>80</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>Horizon Science Academy Toledo</td>
<td>4</td>
<td>24</td>
<td>57</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>Central Academy of Ohio</td>
<td>10</td>
<td>24</td>
<td>60</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>Alternative Education Academy</td>
<td>16</td>
<td>42</td>
<td>86</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>The Maritime Academy of Toledo</td>
<td>4</td>
<td>25</td>
<td>61</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>Northpointe Academy</td>
<td>4</td>
<td>23</td>
<td>66</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>Toledo Accelerated Academy</td>
<td>6</td>
<td>28</td>
<td>57</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Life Skills Center of Toledo</td>
<td>16</td>
<td>42</td>
<td>86</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>Allied Health Academy</td>
<td>6</td>
<td>27</td>
<td>70</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Horizon Science Academy</td>
<td>2</td>
<td>5</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Polly Fox Academy</td>
<td>13</td>
<td>43</td>
<td>93</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>Bti Academy</td>
<td>6</td>
<td>27</td>
<td>70</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>Summit Academy Second</td>
<td>10</td>
<td>36</td>
<td>72</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Achieve Career Preparatory</td>
<td>6</td>
<td>21</td>
<td>64</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>Autism Model School</td>
<td>7</td>
<td>23</td>
<td>49</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Central Catholic High School</td>
<td>8</td>
<td>34</td>
<td>97</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>Notre Dame Academy</td>
<td>2</td>
<td>24</td>
<td>38</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>St. Francis De Sales High School</td>
<td>5</td>
<td>12</td>
<td>61</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>St. Ursula Academy</td>
<td>0</td>
<td>6</td>
<td>15</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>St. John’s Jesuit High School</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Maumee Valley Country Day</td>
<td>7</td>
<td>18</td>
<td>30</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Toledo Christian Schools</td>
<td>0</td>
<td>24</td>
<td>44</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Emmanuel Christian School</td>
<td>1</td>
<td>8</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Glass City Academy</td>
<td>8</td>
<td>29</td>
<td>59</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>Apostolic Christian Academy</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Autism Academy of Learning</td>
<td>10</td>
<td>44</td>
<td>104</td>
<td>166</td>
</tr>
</tbody>
</table>
Table 4.3: Bus Stops within WMCs Buffer Areas

<table>
<thead>
<tr>
<th>Buffer radius</th>
<th>0.25 mile</th>
<th>0.5 mile</th>
<th>0.75 mile</th>
<th>1 mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bus stops</td>
<td>544/2108</td>
<td>1612/2108</td>
<td>2015/2108</td>
<td>2089/2108</td>
</tr>
<tr>
<td>Percentage of bus stops</td>
<td>25.8%</td>
<td>76.5%</td>
<td>95.6%</td>
<td>99.1%</td>
</tr>
</tbody>
</table>

I also created buffers for WMCs of census tracts to check whether there are enough bus stops within walking thresholds. The results are presented in Table 4.3. It shows us the number and the percentage of TARTA bus stops within the WMCs buffer areas. The percentage of bus stops within 1/4-mile buffer area around WMCs is only 25.8%.

Table 4.4: High Schools and WMCs within Bus Stops Buffer Areas

<table>
<thead>
<tr>
<th>Buffer radius</th>
<th>0.25 mile</th>
<th>0.5 mile</th>
<th>0.75 mile</th>
<th>1 mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of WMCs</td>
<td>81/103</td>
<td>100/103</td>
<td>103/103</td>
<td>103/103</td>
</tr>
<tr>
<td>percentage of WMCs</td>
<td>78.6%</td>
<td>97.1%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Number of schools</td>
<td>33/38</td>
<td>37/38</td>
<td>38/38</td>
<td>38/38</td>
</tr>
<tr>
<td>Percentage of schools</td>
<td>86.8%</td>
<td>97.4%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 4.4 tells us that 81 out of 103 (78.6%) WMCs of census tracts are within 0.25-mile buffer areas around TARTA bus stops, which means there are at least one bus stop are accessible on foot in the 78.6% households in the study area, and it make it possible for high school students living in those 81 census tracts to catch up TARTA buses to attend high school.

Besides, there are as many as 86.8% (33 out of 38) of high schools in the study area within the distance of 0.25-mile buffer around TARTA bus stops, which indicates that there is at least one TARTA bus stop available on foot in 86.8% of high schools.
4.2 Statistical Analysis of Spatial Distribution

In the following section, spatial cluster analysis is employed to explore the high school distribution in study area. In recent days, spatial cluster analysis has been given a great amount of attention as an approach to examine and monitor the situation of disease (Carrel et al., 2009; Rogerson and Yamada, 2009). However, few evidences have witnessed the application of this method in the field of health and travel behavior (Mitra, Buliung and Faulkner, 2010). This study adopts both global and local view of spatial cluster analysis. The combined global and local analyses help us know the spatial distribution of high schools in study area. In this thesis, “Average Nearest Neighbor Analysis” is used as the main method to explore the spatial distribution of high schools.

Global View: In the following spatial distribution test, I select all of the high schools as a global view in study area, and make use of “Average Nearest Neighbor Analysis” in Arc Toolbox. Besides, this tool sets the null hypothesis that there is no difference between a random distribution and the distribution of high schools in the study area.
Table 4.5: Average Nearest Neighbor Analysis Summary

<table>
<thead>
<tr>
<th>Observed Mean Distance</th>
<th>4314.98 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Mean Distance</td>
<td>3873.73 feet</td>
</tr>
<tr>
<td>Nearest Neighbor Ratio</td>
<td>1.1139</td>
</tr>
<tr>
<td>z-score</td>
<td>1.360897</td>
</tr>
<tr>
<td>p-value</td>
<td>0.173546</td>
</tr>
<tr>
<td>Input Feature Class</td>
<td>high schools</td>
</tr>
<tr>
<td>Distance Method</td>
<td>Euclidean distance</td>
</tr>
<tr>
<td>Study Area</td>
<td>2340901982 square feet</td>
</tr>
</tbody>
</table>
Figure 4-9 and Table 4.5 are the outcomes of global view spatial cluster test. When I examine the p-value of 0.1735, and given the z-score of 1.36, the pattern does not appear to be significantly different than random. Therefore, I do not reject the null hypothesis that all of high schools are randomly distributed in global view.

Local View: By re-examining the high schools distribution map (Figure 3-1 and Figure 3-2), I find out a phenomenon that some of the high schools are clustered in locally limited areas. For example, the Euclidean distance between Whitmer High School and Autism Model School is as short as 0.3 mile; the straight line length from St. Ursula Academy and Ottawa Hills High School are only 0.38 mile. What is even more is that three high schools reside in the Upton Avenue and Marne Avenue intersection area. Finally, when I zoom in the downtown area, especially the area enclosed by N. Detroit Street, Monroe Street, S. Summit Street and Cherry Street, I discover that in total 8 high schools in the enclosed area.

One of the most important, but also most forgettable procedures in the following spatial cluster test is that one need to maintain the area at the same value as one set before, since average nearest neighbor method is considered as an “area sensitive” calculation, which means a slight change of study area might lead to huge different results in this test (ArcGIS Resource Center, 2012). Hence, the study area should always be kept fixed.
Table 4.6: Average Nearest Neighbor Analysis Summary 2

<table>
<thead>
<tr>
<th>Observed Mean Distance</th>
<th>1349.72 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Mean Distance</td>
<td>6246.20 feet</td>
</tr>
<tr>
<td>Nearest Neighbor Ratio</td>
<td>0.2161</td>
</tr>
<tr>
<td>z-score</td>
<td>-5.81</td>
</tr>
<tr>
<td>p-value</td>
<td>0.000001</td>
</tr>
<tr>
<td>Input Feather Class</td>
<td>high schools</td>
</tr>
<tr>
<td>Distance Method</td>
<td>Euclidean distance</td>
</tr>
<tr>
<td>Study Area</td>
<td>2340901982 square feet</td>
</tr>
</tbody>
</table>
Figure 4-10 and Table 4.6 are the results of local view spatial cluster test. When I examine the p-value of 0.000001, I find out that it is less than any of three significance levels (0.01, 0.05 and 0.1). So I could easily conclude that they are statistically significant and null hypothesis can be rejected, which means the high schools distribution in local view is not random. At the same time, given the z-score of -5.81, this spatial distribution pattern is clustered in local view as I expected.

4.3 Accessibility Analysis to High Schools

One of objectives of this study is to make accessibility map at the census tract level to evaluate the TARTA service quality. Unlike the spatial accessibility analysis for persons who own automobile, some of census tracts in this study are manually defined as “inaccessible” areas because of the unreasonable walking distance. For example, 22 out of 103 (21.4%) census tracts in the study area are inaccessible since the straight line distance between WMCs to the nearest bus stop surpass 0.25 mile. Likewise, 5 in 38 (13.2%) high schools are also “inaccessible” for the same reason (Tables 4.4 and 4.7). Selecting accessible bus stops and high schools could be easily achieved with the assistance “Select by Location” tool in ArcGIS, in which I select the high schools that are not within the distance of 0.25 mile around the TARTA bus stops. The names of these five high schools are: Sylvania Northview High School, Sylvania Southview High School, Ottawa Hills High school, St. Ursula Academy and Toledo Christian School. Among five inaccessible high schools, Toledo Christian School is located at the intersection of Brookford Dr. and State Route 25; two of them are in Sylvania area, and
one is in Ottawa Hills census tract. The five high schools in study area categorized as “inaccessible high schools by walking” are listed in the Table 4.7 as follows:

Table 4.7: Inaccessible High Schools by Walking from TARTA Bus Stops

<table>
<thead>
<tr>
<th>School District</th>
<th>Count</th>
<th>Name of high schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toledo</td>
<td>2</td>
<td>Toledo Christian School; St. Ursula Academy</td>
</tr>
<tr>
<td>Ottawa Hills</td>
<td>1</td>
<td>Ottawa Hills High School</td>
</tr>
<tr>
<td>Sylvania</td>
<td>2</td>
<td>Northview High School; Southview High School</td>
</tr>
</tbody>
</table>

Likewise, I also need to select the accessible census tracts in the study area by checking whether these population-weighted centroids, or the WMCs, are resided within the 0.25 mile TARTA bus stops buffer areas. But the first and foremost question is what, and where the walking-accessible census tracts are.

There are 81 in 103 (78.6%) census tracts in the study area being labeled as the “accessible” tracts by walking, which means that WMCs of these 81 census tracts are within 0.25 mile distance from at least one TARTA bus stop. The rest of 22 census tracts (21.4%) are labeled as “inaccessible” on foot. Although all of these 22 WMCs are not accessible on foot, some blocks in these inaccessible census tracts are close enough to TARTA bus stops, or even within the quarter mile buffer. But, in this thesis, I evaluate the accessibility at the census tract level.
Examining Figure 4-11 in deep shows that Ottawa Hills is not accessible to public transit by walking at all, and most of bus stops are located outside this area (Figure 4-1). As to Sylvania area, more than 50% census tracts are labeled as “inaccessible” by walking under the condition of 0.25 mile walking limit (5 in 9 census tracts), and there are only 164 out of 2108 TARTA bus stops in that area. For example, the minimum straight line distance from Sylvania Northview High School to its nearest TARTA bus stops is about 0.44 mile, and walking-accessibility situation goes worse when I analyze Sylvania Southview High School. The shortest walking distance from this school to a
TARTA bus stop is 0.69 mile. Toledo Christian School is better than others with its minimum walking distance of 0.26 mile to its nearest TARTA bus stop.

The remaining of this chapter talks about the on-road distance from each household (origin) to high school (destination). It is a factor which might significantly affect the accessibility analysis results. Based on the principle of distance decay effect discussed in Chapter Two, the possibility of interaction between each household and high school will decline to a degree as the distance increases. In this research, I created 5-mile on-road-distance buffer for the calculation and evaluation of accessibility score. By making use of Equation 3-4, I could get a table about the accessibility score in the study area (Table 4.8). In this table, INPUT_FID is made to identify the WMCs and NEAR_FID is for high school locations; the third to fifth column are distance (mile), distance$^2$ and $1/\text{distance}^2$ respectively. The last columns of Table 4.8 is the total accessibility index I get by the method of Visual Basic programming presented in last section of Chapter Three, which is run in the environment of Excel spreadsheet. It helps me to sum up the value of $1/\text{distance}^2$ field with the same INPUT_FID.
One of the limitations of employing on-road straight line distance to calculate accessibility is it does not represent the actual travel distance (Zhao et al., 2003), but this method still could be used to estimate the accessibility index for the study area. The schematic diagram of calculating accessibility is presented in Figure 4-12. From Figure 4-12 one could visually see accessibility of the WMC in blue to the three walkable (0.25-mile buffer) high school locations in the study area is measured by summing up the value of $1/\text{distance}^2$ field in Table 4.8.
Figure 4-12: Schematic Diagram of Calculating Accessibility
Figure 4-13: TARTA Public Transit Accessibility Map

Figure 4-13 explores that census tracts with the highest accessibility scores are Tract 2700 and Tract 1302. Tract 2700 is located in the downtown area, and it contains three high schools within its boundary. It also makes sense for Tract 1302 with highest score since it is located in the geographic center in study area. Figure 4-13 also shows that the census tracts with the lowest accessibility score are distributed in Sylvania, southwest of Toledo and northeast of Toledo.

By comprehensive analysis to the TARTA public transit accessibility at the level of census tract, I could easily get a conclusion as follows:
(1) Sylvania area shows low level of public transit accessibility featured by either “inaccessible census tract by walking” (5 in 9 census tracts) or “lowest accessibility scores” (4 in 9 census tracts) in the study area.

(2) Some census tracts with high accessibility scores are spatially clustered in the downtown area. Examining the downtown area enclosed by N. Detroit Street, Monroe Street, S. Summit Street and Cherry Street, this research explores the existence of several high schools and existence of several TARTA bus stops both make great contributions to the higher accessibility score in that area. Some census tracts, for instance 1302, also own high accessibility score because it is located in the geographic center of the study area.

The accessibility indices presented in Table 4.8 and Figure 4-13 are based on the “raw” accessibility value without normalization methods (such as Log 10, which is feasible and more readable because it reduces the values’ huge difference), mainly due to the fact that four accessibility indices are less than 1 individually, which will lead to the negative value if Log 10 normalization is adopted.
From Figure 4-14 one could see that there are three high schools with highest accessibility index in the study area, and the names of these three schools are: Central Academy of Ohio, Life Skills Center of Toledo and Alternative Education Academy. Similarly, the locations of high schools with highest accessibility index are in Tract 2700 and Tract 1302 as the highest accessibility census tracts in Figure 4-13.

Based on the statistical data I presented in Table 4.4, one can see that the percentage of WMCs and high schools within the buffer areas around high schools is 100% if I increase the buffer radius from quarter mile to 0.75 mile. To eliminate the effect of
minimum walking distance I set before, I assume that all of persons in the study area are willing to walk up to 0.75 mile to catch up TARTA public transit facilities for commuting to schools. I increase the walking threshold as many as three times as the minimum (0.25 mile), which is 0.75 mile with an estimated travel time of 15 minutes on foot, to examine the accessibility score under that assumption. Hence, all of 103 WMCs and 38 high schools are included in the accessibility calculation. At the same time, I also use 5-mile as the on-road-distance buffer radius. The map of this accessibility is presented below:

Figure 4-15: TARTA Public Transit Accessibility Map (0.75 Mile Buffer)
Based on the observations Figure 4-15, one can see that the pattern does not change a lot compared to Figure 4-13 but Ottawa Hills, and it has become an area with high accessibility score.

4.4 TARTA Survey Result

From hundreds of TARTA existing users’ survey respondents, I especially selected records of those interviewees as my samples whose main purpose in using TARTA bus was to “commute to school”. The first pie chart shown by Figure 4-8 indicates that nearly two in three people in the study area prefer to take TARTA bus as their routine commuting tool for school on a daily basis.

![Pie chart](image)

Figure 4-8 Frequency of TARTA Riders for School
Figure 4-9 shows that the proportion of TARTA riders who take less than 15 minutes for commute to schools is almost 20%, and that about 54% of students could reach their schools within 30 minutes from homes.

![Figure 4-9 Total Travel Time from Home to School by TARTA (Minutes)](image)

From the standpoint of urban planning, “block” has long been considered as the smallest unit encircled by main streets ([http://en.wikipedia.org/wiki/Block](http://en.wikipedia.org/wiki/Block), 2012). Since the size or length of an individual block varies greatly among different cities, it’s impossible for one to set a standard distance for a block. Likewise, a block length shows a discrepancy within a city. By examining the block file downloaded from the U.S. Census Bureau, I discovered that the average length of individual block is about 163.52 meter or about 0.1016 mile in the study area. By applying the principle of people’s maximum walking distance for catching public transit, which is 0.25 mile (about 400
meters), it is apparent that the highest distance from home to TARTA bus stops should not be more than 2 blocks in the study area. Summing up the percentage of “Less than 1 block” and “1-2 blocks” together, one could see the total percentage of students who live in reasonable walking distance is 63.47% (Figure 4-10). Unfortunately, it was impossible to prove whether the percentages of walking distance and time would closely match since TARTA questionnaire asks about only the total trip hour in their survey, instead of walking minutes from home to TARTA bus stops.

![Walking Distances to TARTA Bus Stops](image)

Figure 4-10   Walking Distances to TARTA Bus Stops

Figure 4-11 depicts that about three in five students (57.69%) are able to arrive at school by using only one bus. Figure 4-12 shows that the peak hour in the morning (7:00-9:00 AM) is the time when three out of every five (58.33%) school-bound trips begin.
Figure 4-13 presents the average TARTA service rating for commuting to and from schools. There are 16 categories in total with the average overall evaluation of TARTA service score of 3.56 out of 5.00, among which I focus on “distance to stop from home”
category. Interviewees in study area hold the point of view that walking distance should be scored 3.2 out of 5.00. The two categories with lowest average evaluation score I have are “Shelters at stops” and “Cleanliness of Buses” with scores of 2.52 and 2.55 respectively. Both of them should be improved in the future, such as keeping the buses clean is an important factor for TARTA riders.

![Figure 4-13 Average TARTA Service Rating for School](image)

The Statistical Package for the Social Sciences (SPSS) is used to further explore the relationship between any of two variables in the TARTA service rating database. Person’s Correlation Coefficient and Spearman’s Correlation Coefficient are two most commonly accepted methods to explore the linear relationship between two variables.
Application of Person’s Correlation Coefficient should be based on the assumption that the variables are normally distributed and the data is continuous; while Spearman’s Correlation Coefficient is applied for categorical data analysis. In the following analysis, I use Pearson’s since the type of data is continuous. The value range of Pearson’s Correlation Coefficient varies from -1 to +1; 0 represents the weakest relationship, while ±1 is a sign of strongest association; meanwhile, the absolute value less than 0.3 are considered weak, and the absolute value more than 0.7 are recognized strong (Cronk, 2012).

Table 4.9 illustrates that there are strong relationships among three variables: safety and security at stops, safety and security on bus, and connections between buses, and all of these absolute values of correlation coefficient are more than 0.7. At the same time, “shelters at stops” is strongly related to “safety and security at stops” with a correlation coefficient value of 0.758. Another pair of variables with strong connection I see is “helpfulness of drivers” and “helpfulness of phone staff” with a highest correlation coefficient of 0.790.
Table 4.9: Strong Linear Relationship Analyzed by Pearson’s Correlation Coefficient

<table>
<thead>
<tr>
<th></th>
<th>Safety and security at stops</th>
<th>Safety and security on bus</th>
<th>Connection between buses</th>
<th>Shelters at stops</th>
<th>Helpfulness of drivers</th>
<th>Helpfulness of phone staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety and security at stops</td>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td>.712**</td>
<td>.736**</td>
<td>.758**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Safety and security on bus</td>
<td>Correlation Coefficient</td>
<td>.712**</td>
<td>1.000</td>
<td>.704**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connections between buses</td>
<td>Correlation Coefficient</td>
<td>.736**</td>
<td>.704**</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelters at stops</td>
<td>Correlation Coefficient</td>
<td>.758**</td>
<td></td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td></td>
<td>.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helpfulness of drivers</td>
<td>Correlation Coefficient</td>
<td></td>
<td>1.000</td>
<td>.790**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helpfulness of phone staff</td>
<td>Correlation Coefficient</td>
<td></td>
<td>.790**</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
The last key question this study addresses is how 15 TARTA service ratings factors affect the overall TARTA service rating. The final output illustrates that there is a significant linear relationship between 15 service rating factors and overall TARTA service with the R-square value of 77.4%. Table 4.10 shows us the multiple linear regression coefficients together with their significance levels, from which we know that four out of 15 independent variables are considered as significant predictors at the significance level of 0.05. These predictors are: cleanliness of the buses, safety and security on bus, shelters at stops and driving skills of bus operator.

Apparently, TARTA bus users believe that whether the bus is clean is very important to them in real world. Safety on bus as well as shelters at stops are also playing vital roles on high school students’ decision about whether take TARTA bus or not. Driving skills of bus operator, the predictor with highest $t$ score of 3.425, is also considered as an essential factor for TARTA student commuters.
Table 4.10: Multiple Linear Regression Coefficient Results

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>-0.046</td>
<td>-0.085</td>
<td>0.933</td>
<td></td>
</tr>
<tr>
<td>Frequency of service</td>
<td>0.020</td>
<td>0.024</td>
<td>1.37</td>
<td>0.892</td>
</tr>
<tr>
<td>Cleanliness of the buses</td>
<td>0.380</td>
<td>0.436</td>
<td>2.476</td>
<td>0.017</td>
</tr>
<tr>
<td>Connections between buses</td>
<td>0.131</td>
<td>0.140</td>
<td>0.656</td>
<td>0.518</td>
</tr>
<tr>
<td>Safety and security at stops</td>
<td>0.298</td>
<td>0.358</td>
<td>1.520</td>
<td>0.142</td>
</tr>
<tr>
<td>Safety and security on bus</td>
<td>-0.450</td>
<td>-0.569</td>
<td>2.834</td>
<td>0.009</td>
</tr>
<tr>
<td>Buses running on time</td>
<td>0.256</td>
<td>0.346</td>
<td>1.814</td>
<td>0.083</td>
</tr>
<tr>
<td>Time service ends in evening</td>
<td>0.120</td>
<td>0.157</td>
<td>1.059</td>
<td>0.301</td>
</tr>
<tr>
<td>Distance to stop from home</td>
<td>0.066</td>
<td>0.084</td>
<td>0.522</td>
<td>0.607</td>
</tr>
<tr>
<td>Shelters at stops</td>
<td>-0.361</td>
<td>-0.488</td>
<td>2.282</td>
<td>0.032</td>
</tr>
<tr>
<td>The price to ride</td>
<td>-0.260</td>
<td>-0.364</td>
<td>1.883</td>
<td>0.072</td>
</tr>
<tr>
<td>Convenience of schedules</td>
<td>0.085</td>
<td>0.089</td>
<td>0.446</td>
<td>0.660</td>
</tr>
<tr>
<td>Driving skills of bus operator</td>
<td>0.547</td>
<td>0.665</td>
<td>3.425</td>
<td>0.002</td>
</tr>
<tr>
<td>Helpfulness of drivers</td>
<td>-0.203</td>
<td>-0.232</td>
<td>1.128</td>
<td>0.271</td>
</tr>
<tr>
<td>Helpfulness of phone staff</td>
<td>0.089</td>
<td>0.097</td>
<td>0.461</td>
<td>0.649</td>
</tr>
<tr>
<td>Bus routes go where needed</td>
<td>0.362</td>
<td>0.378</td>
<td>1.646</td>
<td>0.113</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Overall TARTA service
This thesis explores public transit, especially bus, as a travel mode for commuting to high schools in Toledo Area in Lucas County, Ohio, including Sylvania, Ottawa Hills and Washington Local School District. One of most important objectives of this study is to conduct a spatial accessibility analysis to high schools by TARTA transit.

Apparently, most of TARTA bus facilities, such as bus stops, are not built within the distance of 0.25 mile around high schools and census tracts’ WMCs, which is usually considered as the most reasonable walking distance a person would like to walk to catch a bus. One could get a conclusion from Chapter Four that the locations of those WMCs with high accessibility index are either in the geographical center of the study area or the high-schools-cluster area (such as downtown). Likewise, the distribution pattern of those excellent accessible high schools is similar to that of WMCs in the study area.

5.1 Recommendation to TARTA

This study provides following recommendations:

1. TARTA should think of providing direct services with minimum transfers or increase service frequency in the morning and afternoon to help school commuters.
2. To make TARTA more accessible to school commuters, it is highly recommended that TARTA should increase the number of bus stops within the distance of 0.25 mile around high schools in the study area.

3. TARTA should try to expand their services to Sylvania, Ottawa Hills, east of Washington Local School District, northeast of Toledo area and southwest of Toledo area.

4. A minor geographic factor that might cause negative effect on public transit ridership is the design style of communities, which should not be “enclosed” by street system or be filled with barriers (Fang Zhao et al, 2003).

5. Make the bus stops more tempting to visually attract persons, instead of ugly bus stops.

5.2 Limitation and future Work

The weight I chose in the method to calculate the weighted mean center for each census tract is population in each block. It would be more convincing if I could use the number of carless persons in each block as the weight since I measure the transit accessibility, although some of people who own cars might choose public transit to commute to school or work.

A future study could compare the TARTA public transit service between 2000 and 2010 in terms of accessibility to schools with a purpose to check whether the accessibility has increased over this decade.
References


(48) TARTA 2010 annual report to the community, 2010.
