Average opportunity-based accessibility of public transit systems to grocery stores in small urban areas

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Abstract: This research studies the accessibility of grocery stores to university students using the public transportation system, drawing from a case study of Fargo, North Dakota. Taking into consideration the combined travel time components of walking, riding, and waiting, this study measures two types of accessibilities: accessibility to reach a particular place and accessibility to reach the bus stop to ride the public transit system. These two accessibilities are interdependent and cannot perform without each other. A new method to calculate the average accessibility measure for the transit routes is proposed. A step-wise case study analysis indicates that one route provides accessibility to a grocery store in eight minutes. This also suggests that the North Dakota State University area has moderate accessibility to grocery stores.

1. Introduction

The US Department of Agriculture defines a food desert as “a low-income census tract where a substantial number or share of residents has low access to a supermarket or large grocery store” (USDA, 2009). University students are a low-income group. It is important from the food security point of view for university students to have access to healthy food options. A grocery store (supermarket) is a place

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PUBLIC INTEREST STATEMENT

Providing accessibility to local businesses is a critical service of public transportation systems. In this study, we used geographic information systems to measure indices that indicate the level of college students’ access to grocery stores in Fargo, North Dakota. All existing public transportation routes and grocery stores in Fargo are investigated with regard to boarding time, transfer time, walking time, and travel time to calculate total traveling costs. We found that all grocery stores are accessible, but some major and specialized stores are too far away for a reasonable round trip. We found that, given the cold weather during the winter, a five-minute walking distance to a bus shelter is appropriate for designing bus routes. Public transit agencies and city planners can use this study and its approach for planning public transportation services.
where they can buy a range of healthy food products. This research studies the accessibility of public transit to grocery stores using the public bus system. A case study of the grocery stores in an area of the city of Fargo, North Dakota, is performed for the development of an average accessibility measure for the transit route.

Accessible is defined as “(of a place) Able to be reached or entered” (U. Oxford, 2012). It is from this word that accessibility is derived, which means the ability to reach a particular place or area (Litman, 2015). This definition is used in two different regards while studying transit system accessibility: (1) Accessibility to reach a particular place, such as a healthcare facility, work place, or grocery store using public transit, and (2) Accessibility to reach the public transit stop to ride the system. It is important to find the accessibility of bus stops based on the population it is serving, to make transit route decisions in urban settings. These two accessibilities are interdependent and cannot perform without each other. If a person wants to start a journey with public transport, he or she decides the place and then selects a point to board the bus to reach his or her destination. Thus, it is important to study both accessibility by measuring walking distance and opportunity to ride the public transit. Litman (2015) in his updated study provides several other meanings of accessibility with respect to different purposes such as engineering, urban economics, pedestrian planning, and social planning.

Important factors affecting accessibility are: mobility, transport options, land use, and affordability (Litman, 2015). Affordability of transit depends on the ability of a person to pay the cost for a particular trip. This personal ability is collectively expressed as the average household income. Public transit system development is focused on providing equal opportunities to all economic groups. Thus, the system should be accessible to all economic groups. Kwan (1998) studied three types of accessibility measures: (1) gravity-type, (2) cumulative-opportunity, and (3) space–time measures. They compare space–time measures with other two measures and also develop a computational algorithm using geographic information systems (GIS). Miller (1999) studied individual accessibility and connected three measures: space–time constraint-oriented approach, attraction measures, and land-use approach. This study provided a measure that reflects locations, distances and travel velocities by urban transportation network. Different classification criteria are presented in Geurs and van Wee (2004). Their criteria are used for accessibility of all modes of transportation. This research focuses on the accessibility of public transit system, thus concentrating on the literature and measures used for public transit system.

This research addresses the issue of the accessibility of the public transit modes from a residential area, combining it with the routing decisions based on the average household income. This accessibility is determined with the help of GIS. The data from the census and economic survey are joined with the spatial data to make routing decisions. A case study of the transit system in the city of Fargo, North Dakota, is performed to learn about accessibility and routing decisions based on average household income. This study focuses on the accessibility of grocery stores to a particular low-income group (university students) by the use of walking and Metro Area Transit Bus (MATBUS) travel.

This study proposes a method to calculate the average accessibility measure for the transit routes. Section 2 describes related efforts in earlier literature. Section 3 provides the methodology and development of the average accessibility measure. Section 4 provides the case study analysis. Section 5 presents results and discusses them in detail. Conclusion and future research are explained in Section 6.

2. Literature review
The literature regarding accessibility to transit system can be divided into three parts: (1) Need for an accessibility study, (2) methods to determine the accessibility of various places using the public transit system, and (3) methods to determine the accessibility to the public transit system.

2.1. Need for an accessibility study
Connecting people to their places of work using public transit has long been a topic of conversation in the transit industry. A vast study of the metropolitan area transit systems in the United States and jobs in those areas was performed by Tomer, Kneebone, Puentes, and Berube (2011). They analyzed jobs in
metropolitan regions and connectivity of those jobs with the help of public transit systems. They provided findings about the residents living in areas with access to public transit. The large metropolitan areas of New York, Los Angeles, Houston, and Washington, DC provide frequent service (every 10 min) through a variety of route combinations. About 30% of jobs can be reached with the public transit within 90 min, which was their threshold of study.

Tomer (2011) stated that even though zero-vehicle households’ areas are well served by public transit systems, they cannot provide ample connectivity with job opportunities. About 90% of 7.5 million zero-vehicle households from the metropolitan United States live in areas served by some kind of public transit system, but only 40% of them have job access within 90 min via transit. Accessibility is also important to reach different places such as healthcare facilities, grocery stores, and educational institutions. Also, it is important to be able to access a public transit system that is within walking distance from a household.

Curl, Nelson, and Anable (2011) review the literature on accessibility with the perspective of planning practitioners in the United Kingdom. They classify accessibility measures into five categories: infrastructure-based, cumulative, gravity-based, utility-based, and activity-based measures. They conclude that though accessibility is given importance in transportation planning, there is a greater need for work based on comparing objective measures and people’s perspective of accessibility.

2.2. Determination of accessibility of various places using public transit system

Different studies have been performed to determine the accessibility of various locations from the public transit system. An important issue of access to healthy food is addressed by Burns and Inglis (2007). They used the GIS accessibility program to evaluate access to healthy and unhealthy foods in the Melbourne metropolitan area of Australia. They found that the areas with low-income households had closer access to fast-food locations, which they considered unhealthy options, while higher income households had better access to grocery stores to buy healthy foods. They state that only 50% of the population dependent on the bus had access to grocery stores within 8–10 min of travel time. They used an extension called accessibility analyst developed by the Centre of International Agricultural Tropica for ArcView GIS 3.2.

In their research regarding cancer patients in the UK, Jones et al. (2008) found an important relationship between accessibility to the transit system and cancer treatment urgency. This study highlights the importance of accessibility in the field of healthcare. Information from the patient register was combined with road network and transit information, and GIS was used to calculate accessibility to surgeries (Lovett, Haynes, Sunnenberg, & Gale, 2002). They found that around 13% of the population could not reach hospitals for surgery using the bus service. They suggested using the patient register with GIS as a planning tool for further research.

Shannon et al. (2006) presented results of an online survey about commuting patterns and transit decisions by the university population in Australia. They found that 30% of students and staff could switch to public transport if the barriers are reduced, thereby providing evidence of potential ridership. They only used online survey data and conducted statistical analysis to acquire the results.

2.3. Determination of accessibility to the public transit systems

The previous section talks about the accessibility to different destinations using public transit system, while this section reviews the literature about the accessibility to public transit system. These studies talk about how people can reach public transit system in order to use it. Salon (2009) used survey data in her study about commuting in the city of New York. She used discrete choice econometrics to estimate a model of the choices of car ownership and commute mode while also modeling the related choice of residential location. A multinomial logistic regression model is used to relate choice of residential neighborhood, car ownership status, and commute transport mode. She proposed if the relative travel time is less for transit than cars, auto ownership and car commuting can be reduced.
An application to perform measurement of public transit supply and needs in the socially disadvantaged area of Melbourne, Australia, was proposed by Currie (2010). He recognized gaps between social needs and transport service. Thus, different policy changes are suggested for transit planning. A study of GIS-based accessibility in Auckland, New Zealand, was performed by Mavoa, Witten, McCreanor, and O’Sullivan (2012). They created a multimodal transit network and combined it with the transit service frequency to calculate actual accessibility. They put forward the importance of transit frequency use in future studies and stated that frequency affects transit usage decisions.

A new method of using GIS to produce accessibility maps is provided by Langford, Fry, and Higgs (2011). They avoided using the criticized method of using buffers and demonstrated a modified two-step floating catchment method as an accessibility measure. A different approach to solve the transit route problem was used by Curtin and Biba (2011). They used a mathematical model to maximize the service value of a route, rather than minimizing cost, called Arc-Node Service Maximization. They performed a case study on the street network in Richardson, TX, and found that their method increases the service of the transit system. Zhao, Chow, Li, Ubaka, and Gan (2003) estimated transit walk accessibility using population, employment data, transit routes, and street configuration. They found that the network ratio method with actual walking distance shows better results than the simple buffer method because of natural barriers in the study region.

Biba, Curtin, and Manca (2010) proposed a new method to determine the population with walking access to transit. They offered a parcel-network method, which used the spatial and aspatial attributes of parcels and the network distances from parcels to bus stop locations. This method also avoids the criticized and unrealistic buffer method. They compared their method with the buffer analysis and network-ratio methods in the case study of transit in the metropolitan area of Dallas, TX.

The current literature highlights the need for accessibility measures for healthy food options. Though there are various efforts for defining accessibility measures based on different perspectives, there is a need for developing a measure based on the actual need of the people and their walking perspective. Thus, we try to develop a modified average accessibility measure for a transit system based on walking distance to the bus stop and income group.

3. Methodology

3.1. Data sources

This study uses two groups of data sets: census and transportation networks. Population and household income data are used for census data. Population shapefiles provided by the U.S. Census Bureau for the year 2010 are used for census blocks (U.S. Census Bureau, 2011, https://www.census.gov/geo/maps-data/data/tiger-line.html). A census block is the smallest geographical unit for which data are presented by U.S. Census Bureau. Household income data of the year 1999 are available from a data-base provided by the University of Wisconsin at Milwaukee (Employment and Training Institute, 2008, https://www4.uwm.edu/eti/PurchasingPower/ETIshapefiles.htm).

Cass County provides a GIS shapefile of roads and other geographic boundaries from the county’s website (Cass County Geographic Information Systems, 2012, https://www.casscountync.gov/county/depts/GIS/download/Pages/shapefiles.aspx). MATBUS, the transit provider in the Fargo area, operates routes and bus stop locations. As destinations for grocery shopping in the study, eight grocery stores were identified and digitized. The stores are three Hornbacher’s (North, South, and 13th Ave.), two Sun Marts (North and South), and two Wal-Marts (13th Ave. and 55th Ave.), and a Cash Wise. Some other grocery stores were excluded in Moorhead, MN, the neighboring city in Minnesota.

3.2. Accessibility measures

The components of riding public transit for grocery shopping are composed of walking time from home of origin $o$ to the closest bus stop $i$ en route ($W_{oi}$) and riding time from a bus stop $i$ to a grocery store of destination $j$ ($R_{ij}$). The riding time can be decomposed into three components: riding time from a starting
bus stop $i$ to a transit station $k$ ($R_{ik}$), transfer time at the transit station for transferring from one bus $j$ to another bus ($Q_k$), and traveling from the transit station $k$ to the destination bus stop $j$ ($R_{kj}$). $W_{jd}$ presents the walking time from the bus stop $j$ to the grocery store $d$ as destination. This time is represented as $Travel_{outbound}$, the traveling time toward destination $j$ in Equation 1:

$$Travel_{outbound} = W_{oi} + R_{ij} + W_{jd} = W_{oi} + (R_{ik} + Q_k + R_{kj}) + W_{jd}$$  \hfill (1)

Therefore, as it is possible to reach the destination with only one trip without transfer, the component $(R_{ik} + Q_k + R_{kj})$ can be zero in that situation. Waiting time at the transfer point will be included as transfer time ($Q_k$), while the first waiting time can be added to the walking time $W_{oi}$. However, the return journey, which is an inbound trip from a grocery store to home, is not always the same as the outbound trip to the grocery store due to route strategies, one-way roads, and other barriers. Thus, the total travel time will be represented as a summation of time toward destination and time from destination to reach origin $i$. This time is given as $Travel_{total}$ in Equation 2:

$$Travel_{total} = Travel_{outbound} + Travel_{inbound}$$  \hfill (2)

The students at North Dakota State University (NDSU) and other higher education institutions in the Fargo–Moorhead area ride the buses fare-free through a U-Pass program. The travel time and convenience likely have significant impacts on the use of transit for grocery shopping. In comparison to the public transit traveling time ($Travel_{total}$), the driving time can be estimated as walking time from home to the parking location ($W_{wp}$) and traveling from the parking location to the grocery store ($R_{pd}$). Driving is faster than riding transit in this region and is also convenient for carrying groceries. However, the cost of driving is approximately $0.771$ per mile for composite average of small sedan, medium sedan, and large sedan considering fuel, maintenance, tires, insurance, license, depreciation, and financing (AAA Association Communication, 2012, [https://exchange.aaa.com/wp-content/uploads/2012/04/Your-Driving-Costs-20122.pdf](https://exchange.aaa.com/wp-content/uploads/2012/04/Your-Driving-Costs-20122.pdf)). Thus, this study assumes the students are sensitive to cost, and students plan to ride public transit despite the cost of time and convenience, so this study focuses on walkability and opportunity-based accessibility.

The accessibility measure referred to as ‘average opportunity accessibility’ is derived from the opportunity measure proposed by Wachs and Kumagai (1973). Opportunity-based measures compute the number of opportunities that someone could have within a certain distance or during some period. A larger number indicates a greater level of accessibility. This model could be written as Equation 3:

$$A_i = \sum_{j} D_{ij} \left( t_s \leq t_0 \right)$$  \hfill (3)

where $A_i$ is the accessibility of origin $i$, $D_{ij}$ is the number of opportunities at destination $j$. Destination $j$ is within a threshold travel time $t_s$ from origin $i$.

This study modifies the accessibility to incorporate the public transit route available and grocery stores served by the transit route. For example, some census block might have one or more service routes with at least one grocery store through one route, while some might not have any public transit service available. Even if some census blocks belong to one or more public transit routes, the routes might not have any grocery store along them. Equation 4 addresses such issues. The public transit routes ($BR_{m}$), which are located within the threshold walking distance from each census block as origin $i$ to the closest bus stops $o$ ($t_s$), are found. The number of grocery stores ($G_d$) through the routes ($BR_{m}$) is summed. Then, the total number of grocery stores is divided by the population in the census block ($POP_i$). In other words, the accessibility for origin $i$ (a census block) equals the sum of grocery store on a route that can be accessed in less than $n$ minutes, divided by the population for origin $i$:

$$A_i = \frac{\sum_{m,w \leq t_s} G_{d(d \in BR_m)}}{POP_i}$$  \hfill (4)
Equation 4 gives the value of average opportunity-based accessibility. It is given by dividing the total number of grocery stores through one bus route with total population in the census blocks through that route within walking distance.

This study connects the average accessibility measure, which is a technical measure, with the population perspective in terms of paying for service and use of the public transit system. This is an important addition as it will be useful for transportation planners.

4. Analysis

The analysis is performed with the help of GIS map development and statistical study. This is presented in three steps. The first step is analysis of the average household income and bus routes in Fargo. The second step is analysis of the total population in census blocks and transit routes 13A and 15. The third step is performing network analysis for generating service areas. A statistical analysis to find accessibility is also performed in this step.

Step 1: Analysis of the average household income and bus routes

The average annual household income is calculated by adding the total annual incomes of households in a given area and dividing it with the total number of households in that particular census area. These data are joined with the shapefile of the census area for visualization. The data for average annual household income is presented in Figure 1. This figure also includes the road network of Fargo and selected bus routes. The GIS map is used to analyze the bus route distribution based on the average annual household income in census block groups. According to U.S. Census Bureau, a census block group is the unit clustering census blocks and contains around 600 to 3,000 people. This map shows the average annual household income is the lowest around the bus routes 13A and 15.

Route 13A travels around North Dakota State University. The majority of the population around this route is made up of students, which explains the smaller average annual household income. This route connects the university to the Fargo downtown area and the Ground Transportation Center (GTC), which is a hub for public transit. Route 15 connects the GTC with the new business developments like West Acres Mall and Wal-Mart. Large numbers of university students frequently use these routes for travel. Thus, this study is focused on the accessibility analysis near routes 13A and 15.

Step 2: Analysis of the total population in census block

The second step analyzes the total population in the census blocks and important MATBUS routes. The main bus stop serving the NDSU campus is located at the south side of the Memorial Union building, where there is a large shelter that most students use when waiting for the bus.

The area grocery stores are located and digitized using their latitude and longitude. The MATBUS routes connecting NDSU and the grocery stores are identified. Figure 2 shows routes 13A, 11, 14, 16, 23, 25, and 15 and the total population in census blocks. The student population use MATBUS to travel to different grocery stores.

Step 3: Network analysis

The analyses in Steps 1 and 2 found the seven important routes to be 11, 13A, 14, 15, 16, 23, and 25. There is a moderate or high population in the census blocks around NDSU. This study assumed that a majority of this population is the student population. The average annual household income of this population is also smaller. Thus, it is assumed that this student population needs transit access to travel to different places.

The walking accessibility of this population to reach a transit stop is studied in this step. The Network analyst is the default functionality in the ESRI ArcGIS software. This functionality has different methods...
such as closest facility analysis, service area, and vehicle routing problem. This study uses service area and closest facility methods. The service area method is used to study the accessibility based on walking distance, thereby presenting WT in the total travel time. In the city of Fargo, MATBUS allows flagged stops at all intersections on their routes, so they are assumed as the intermediary destinations. The service area method uses the actual route information for drawing the service area from the specific facility. The service area is the polygon around the facility, which is accessible from within that polygon.

Gates, Noyce, Bill, and Van Ee (2006) stated that the four feet per second (feet/s) walking speed can be used near the college campus. It is assumed for this study that the pedestrian walking speed is 4 feet/s. Two different times are assumed as the different willingness to walk to the transit stop. Five minutes and slightly more than 10 min are considered as two walking times for this case study. This gives two different distances to use in the GIS analysis. If the walking time is 5 min, 1,200 feet is the walking distance (5 min × 60 × 4 feet/s = 1,200 feet), and the walking distance 2,500 feet (10.5 min × 60 × 4 feet/s ≈ 2,500 feet) is for slightly more than 10 min.

Distances of 1,200 feet and 2,500 feet are used to plot the service area. For the service area, maximum distances traveled by the available path are 1,200 feet and 2,500 feet. The road network in the...
The city of Fargo is assumed to have sidewalks for the pedestrians to reach the transit stops. In reality, some streets may not have sidewalks, reducing pedestrian accessibility, but for the area being studied, most of the streets have sidewalks. Instead of using straight-line distances, a service area method based on actual route by avoiding natural and man-made barriers is proposed to be more suitable for the accessibility study. The service area method uses the sidewalk network as the route network. Thus, it has fewer obstacles and the actual distance and time traveled can be calculated.

5. Results and discussion

5.1. Results

It is found that there are four groups of routes, which connect NDSU to the following area grocery stores: Hornbacher's, Sun Mart, Wal-mart, and Cash Wise. Service areas around these routes are formed using walking distances of 1,200 and 2,500 feet. For example, Figure 3 shows the service areas around routes 15 and 13A in (a) and (b), respectively. A major portion of Route 15 is along 13th Avenue South for both directions (Figure 3(a)). The route provides service between the GTC downtown and the West Acres Shopping Center on the west side of the route.
Route 13A starts from the GTC and provides direct service to the NDSU campus and Sun Mart North (Figure 3(b)). Route 13A, when using a 1,200-feet walking distance, serves 14,577 people through 94 possible stop locations. Each stop might serve 155 people. When using the 2,500-feet walking distance, Route 13A serves 21,915 people, and each stop of the route might serve 233 people (Table 1).

For the walking distance of 1,200 feet, the accessibility of the census blocks along the routes for different service areas are calculated with Equation 4 developed in the methodology. For example, Route 13A with service area for 1,200-feet walking distance serves a total population of 14,577. The average accessibility can be calculated using GIS analysis. For example, one census block near NDSU through route 13A has a population of 95 and it reaches 1 grocery store. Thus, using Equation 4 this block has accessibility of 0.0105 (1/95). A summation of all census blocks average accessibilities for all census blocks along Route 13A equals 0.129, which is higher than that along Route 11 but lower than those along Routes 14 and 15. Route 14 provides the highest accessibility among the routes; however, this route does not have grocery stores along the route using a combination of two or more routes.

For the walking distance of 2,500 feet, the average accessibility of the census blocks along Route 13A is the highest (0.226) since both Sun Mart North and Hornbacher’s North are located in the service area.

This accessibility is visualized with the help of GIS maps in Figure 4: (a) for the 1,200-feet walking distance and (b) for the 2,500-feet walking distance. It is difficult to connect Hornbacher’s South and Sun Mart South with NDSU by transit, showing low accessibility for both of 1,200-feet and 2,500-feet walking distances. Students have to take three different routes to reach these two grocery stores through 13A–15–23 routes. Figure 4 shows the transferring at GTC from Route 13A to 15 and at West Acres Shopping Center from Route 15 to 23.

Wal-Mart 13th Ave. plays an important role in grocery shopping for the lower income level in the city. The store is accessible with routes 13A and 15 for NDSU students by transferring from route 13A to 15 at the GTC. Route 13A is highly accessible to students to the stores, but the route must be linked to Route 15 to reach Wal-Mart 13th Ave. and Target (Figure 4(a)).

The newest grocery store in the Fargo area is Wal-Mart 55th Ave. at the south edge of the city. The probability that NDSU students will ride a transit route, which is far from the university campus, or travel for grocery shopping by walking long distances is very low. Though Wal-Mart 55th Ave. is accessible by connecting routes of 13A–15–23 from the university, the probability of students going there for shopping is very low.

Routes 13A and 11 connect NDSU to Sun Mart and Hornbacher’s North. Sun Mart North is the closest grocery store to the students, taking 12 min without stopover at the transit center (Table 2). The routing decisions are made with the help of bus speed and distance in miles for the routes. The ArcGIS® Network Analyst tool was used to find routes from NDSU to grocery stores with the shortest travel times. The average effective bus speed in Fargo is assumed as 15 miles/h. This is assumed with the standard delays for the stoppage for passengers. Total travel time and distance traveled is presented in Table 2.

The closest grocery store is Sun Mart North. It takes five to ten minutes walking and approximately three minutes by bus without any transfer. The farthest store is Wal-Mart 55th Ave., which requires five to ten minutes walking plus 10-min transfer time, and 38-min riding in bus; thereby it takes 52.78 min in total.

Routes 13A and 11 run parallel from downtown to the north of the city. Hornbacher’s North is located near the edge of route 13A (Figure 5). If only the route 13A is used to reach Hornbacher’s North, it takes five minutes more on foot in a 2,500-feet walking distance (see Figure 5(b)). From the analysis, Route 13A
Figure 3. Public transit service areas for route 15 (a) and 13A (b).
Table 1. Walking distance and accessibility

| Walking distance (feet) | Route | Service population (person) | Average accessibility | Grocery stores reachable          |
|------------------------|-------|------------------------------|-----------------------|-----------------------------------|
| 1,200                  | 11    | 11,868                       | 0.078581              | Hornbacher’s North                |
|                        | 13A   | 14,577                       | 0.129564              | Sun Mart North                    |
|                        | 14    | 14,389                       | 0.153888              | N/A                               |
|                        | 15    | 16,706                       | 0.144107              | Wal-Mart 13th Ave./Target          |
|                        | 16    | 13,613                       | 0.091632              | Cash wise                         |
|                        | 23    | 10,577                       | 0.048672              | Wal-Mart 55th Ave.                |
|                        | 25    | 15,884                       | 0.055923              | Hornbacher’s South/Sun Mart South |
| 2,500                  | 11    | 21,117                       | 0.148918              | Hornbacher’s North                |
|                        | 13A   | 21,915                       | 0.22615               | Sun Mart North/Hornbacher’s North |
|                        | 14    | 21,917                       | 0.211664              | N/A                               |
|                        | 15    | 28,480                       | 0.206012              | Wal-Mart /Target                  |
|                        | 16    | 19,933                       | 0.158101              | Cash wise                         |
|                        | 23    | 14,351                       | 0.089228              | Wal-Mart 55th Ave.                |
|                        | 25    | 23,129                       | 0.067771              | Hornbacher’s South/Sun Mart South |

Figure 4. Accessibility of Wal-Mart 55th Ave. with route 23: (a) 1,200-feet walking distance and (b) 2,500-feet walking distance.
is the only route to reach a grocery store without stopover. In order to save transfer time and increase ease of ride for grocery shopping, Route 13A can be extended to Hornbacher’s North and provide connection point to the route 11.

### 5.2. Discussion

When the study assumes that a student is not making any money, the choice of taking the public transit for grocery shopping at a cost of $0 seems most favorable (Figure 6). This trend continues till the student is willing to pay $4 per hour, which is equilibrium cost for $0.50 vehicle mile cost and free ride for the public transit considering time value. At this threshold, the student is indifferent to choosing the public transit or driving a car at a cost of $0.50 per mile. If the driving cost per mile is $0.80, this threshold is shifted to a cost of $5. The equilibrium cost increases to $6 if the driving cost increases to $1.00 per mile due to fuel price or maintenance cost. In other words, when the vehicle driving cost per mile increases to $1.00 per mile and a student earns $10 per hour, the student is more likely to drive for grocery shopping at Wal-Mart 13th Ave.

Due to the importance of the connectivity of the public transit to places in the city, the mobility and transit service plan play an important role in grocery shopping. Along 13th Ave. South, Wal-Mart, Hornbacher’s, and Cash Wise are locations that provide fresh foods. For example, if the city transit system adds a weekend route from NDSU to the West Acres Shopping Center mall area, the total travel

### Table 2. Route connections and travel time from the university to the grocery stores in town

| Walking distance (feet) | Destination     | Connections | Travel distance (miles) | Boarding (min, $R_s + R_k$) | Transfer time (min, $Q_s$) | Walking time (min, $W_s$) | Travel time (min) | Cost ($) for traveling |
|------------------------|-----------------|-------------|-------------------------|------------------------------|----------------------------|--------------------------|-------------------|------------------------|
| 1,200                  | Sun Mart North  | 13A         | 0.7740                  | 3.0960                       | 0                          | 5                        | 8.0960            | 2.70                   |
|                        | Hornbacher’s North | 13A–11   | 4.3940                  | 17.5760                      | 5                          | 5                        | 27.5760           | 9.19                   |
|                        | Hornbacher’s South | 13A–14–25 | 4.4920                  | 17.9680                      | 10                         | 5                        | 32.9680           | 10.99                  |
|                        | Hornbacher’s 13th Ave. | 13A–15 | 4.7640                  | 19.0560                      | 5                          | 5                        | 29.0560           | 9.69                   |
|                        | Sun Mart South  | 13A–14–25 | 5.4190                  | 21.6760                      | 10                         | 5                        | 36.6760           | 12.23                  |
|                        | 13th Ave.       | 13A–25     | 5.6040                  | 22.4160                      | 5                          | 5                        | 32.4160           | 10.81                  |
|                        | Wal-Mart 55th Ave. | 13A–25–23 | 9.4450                  | 37.7800                      | 10                         | 5                        | 52.7800           | 17.59                  |
|                        | Cash Wise       | 13A–16     | 4.6832                  | 18.7327                      | 5                          | 5                        | 28.7327           | 9.58                   |
| 2,500                  | Sun Mart North  | 13A         | 0.7740                  | 3.0960                       | 0                          | 10                       | 13.0960           | 4.37                   |
|                        | Hornbacher’s North | 13A–11   | 4.3940                  | 17.5760                      | 0                          | 10                       | 27.5760           | 9.19                   |
|                        | Hornbacher’s South | 13A–25 | 4.4920                  | 17.9680                      | 10                         | 10                       | 37.9680           | 12.66                  |
|                        | Hornbacher’s 13th Ave. | 13A–15 | 4.7640                  | 19.0560                      | 5                          | 10                       | 34.0560           | 11.35                  |
|                        | Sun Mart South  | 13A–25     | 5.4190                  | 21.6760                      | 10                         | 10                       | 41.6760           | 13.89                  |
|                        | Wal-Mart 13th Ave. | 13A–25 | 5.6040                  | 22.4160                      | 5                          | 10                       | 37.4160           | 12.47                  |
|                        | Wal-Mart 55th Ave. | 13A–25–23 | 9.4450                  | 37.7800                      | 10                         | 10                       | 57.7800           | 19.26                  |
|                        | Cash wise       | 13A–16     | 4.6832                  | 18.7327                      | 5                          | 10                       | 33.7327           | 11.24                  |

Note: Cost is computed by the labor expense of $10 per hour for traveling for a student.
Figure 5. Major routes to reach Hornbacher’s and Sun Mart North: (a) 1,200-feet walking distance and (b) 2,500-feet walking distance.

Figure 6. Sensitivity analyses for a trip to Wal-Mart 13th Ave. that compares riding a public transit system with driving a vehicle.
time will be 22 min at a bus speed of 15 miles/h (11 min for 30 miles/h) and it increases the mobility and convenience for the student by providing them opportunity to reach fresh foods from Wal-Mart. In addition to the extension of the routes, Hornbacher’s 13th Ave. can be added to the proposed transit service route with an additional bus stop.

6. Conclusion and future research
This study shows that MAT BUS in the city of Fargo has adequate routes in the areas where the average annual household income is lower. All grocery stores in the Fargo area are accessible by bus within 8–53 min of one-way travel time for North Dakota State University students.

According to this study, if the pedestrian is willing to travel for 10 min to reach the transit stop, a large area can be considered within the accessible distance of a transit route. This study further shows that Sun Mart North is the closest grocery store to NDSU considering travel time, whereas Hornbacher’s North has the highest accessibility (Route 13A). This can be explained by the large residential population surrounding Hornbacher’s North. Wal-Mart 55th Ave. is the farthest grocery store from NDSU, and it also is the least accessible since it is located in the newly developing zone.

Considering the cold weather in the city of Fargo, it is practical to use five minutes as the walking distance and the service areas for 1,200 feet (365 m) instead of using 2,500 feet. Therefore, it is important to study the shelter locations. Future research could be conducted to understand how many shelters are available and the accessibility of those shelters.

This research presents an important model and the analysis for the accessibility problem with the help of GIS. This study can be applied to public transit planning and the division of public affairs of the city and the metropolitan organizations. This work can guide the studies to calculate the accessibility of different zones in the new development. Also in urban planning this can help to provide insights into the transit routes and placement of grocery stores. This research can be replicated for other transit agencies which are serving lower income groups.

A survey is proposed for future research to gather inputs from the diverse population. This survey will collect inputs about the willingness of walking to the transit stop, the walking distance, and the time taken for walking. This survey will enhance data about inclination to waiting for a bus at a stop and the time for travel in a bus. The survey data could be used in the GIS study to get the actual distance traveled by individuals to reach the bus. It is important to compare and connect the technical measures and people’s perspectives. This proposed survey will help future studies to fulfill this requirement.

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