

E-Commence: Visualizing a Growing Future of Tackling the Food Deserts Problem

**Henry Washington , Steven Jiang , Lauren Davis
and Hyun Nam Kim**

Department of Industrial and Systems Engineering
North Carolina A&T State University
Greensboro, NC, USA

Primary Contact

Steven Jiang , , xjiang@ncat.edu

Abstract

Food insecurity is a problem that should not be overlooked in America. In 2022, about 1.3 billion people were food insecure, an increase of 10% from the previous year. Food deserts, an area with low income and low access to nutritious foods, can be characterized by 5A's: availability, accessibility, accommodation, affordability, and acceptability. As more investments go into building infrastructure for population growth, the local food industry must expand for both current and new residents. One strategy to combat food deserts is to use the Internet and e-commerce like online food services can contribute to solving food insecurity. From Generation X to Millennials to Generation Z, the adoption of the Internet is rapid. However, these services have additional costs for the consumer. The goal of this research was to examine the current e-commerce solutions to food deserts in a local area and review the literature on how e-commerce can alleviate food deserts. Data were collected from published government and company sites. Results reveal Internet accessibility continues to be an issue for reliable e-commerce use. E-commerce can alleviate food deserts by reducing the cost for both consumers and businesses, accommodating various groups of people, and focusing on rural areas.

Keywords

Food desert, E-commerce, Food Insecurity, Visualization.

1. Introduction

1.1 Background

Food insecurity is an economic and social condition of a household lacking adequate access to nutritious, healthy food access to adequate food, has become a large public health concern (USDA 2017). Studies have shown that food insecurity is associated with health conditions such as obesity, heart disease, and diabetes (Dutko et al. 2012; Haskell, 2022). Food insecurity is more profound in food deserts, areas where the nearest supermarket is more than one mile away in urban areas or ten miles away in rural areas (USDA 2023). Food deserts are in both urban and rural areas across the U.S. The United States Department of Agriculture (USDA) reported that larger levels of poverty increase the likelihood of a food desert's presence regardless of the area type, rural or urban (Dutko et al. 2012). People living in the food desert often need to do grocery shopping at gas stations or "mini-marts" where typically overpriced junk food is sold.

The USDA measures food deserts using census tract, a subdivision of a county with a population between 1,000 and 8,000 people. A census tract that has low income (The poverty rate is greater than or equal to 20 percent, or the median family income is less than 80 percent of the state median family income), low access (At least a third of census tract population lives greater than a mile from a supermarket and grocery store for urban areas or 10 miles for rural areas) is considered a food desert (Ver Ploeg et al. 2011). There are food desert alternative definitions where the distance for urban tracts to a supermarket or grocery store is 0.5 miles instead of 1 mile, while a rural tract's distance remains as 10 miles. A third definition is, while the urban tract distance remains at 1 mile, the rural tract distance is 20 miles.

Based on the 2000 Census, the USDA has found 6,500 food desert tracts in the U.S. with over 20 million people live food deserts (Ver Pleog et al. 2015).

This research project focuses on Mecklenburg County, North Carolina of the United States, which contains the city of Charlotte and the surrounding suburbs. A small percentage of the county is considered rural. Mecklenburg County currently has 15% of its 2.8 million population living in a food desert, which is higher than the national average of 11% and the North Carolina's state average of 13% (McFadden, 2020). Solutions to food desert often focuses on physical locations of grocery stations and their proximity to their customers (Gordon et al. 2011, Handbury et al. 2015, Ver Pleog et al. 2015). When investigating Mecklenburg County specifically, the literature available on food deserts solutions focus on farmers markets, urban farms, community co-ops and the opening of private grocery stores (Harris & Boger 2020, Kerrick et al. 2018, Mecklenburg County, n.d.).

Currently, there is little research on e-commerce solutions in relation to food deserts in Mecklenburg County. Most research focuses on physical stores (supermarket, supercenters, etc.), urban farms, farmer markets, and community efforts. There are areas within Charlotte's city limits that do not contain a physical location for a grocery store so consumers must drive out of their neighborhoods or their census tract to find fresh foods. Alternate solutions like e-commerce can bridge a gap in services for consumers, especially with the growth of online services and consumers reliance on the Internet. These obstacles come in the form of online food service costs, transportation costs, and lack of access to the Internet. This research focuses on the current obstacles consumers in Mecklenburg encounter when trying to use e-commerce services. In addition, the current literature on food deserts and ecommerce is reviewed on how ecommerce can address the food desert problem.

1.2 Objectives

The objectives of this research are to explore how modern e-commerce solutions can apply to tackling food deserts and food insecurity in a local community.

2. Literature Review

Food desert is defined as an area in the United States with limited access to affordable and nutritious food, particularly such an area composed of predominately lower-income neighborhoods and communities (Institute of Medicine & National Research Council 2009). Three patterns have emerged in the way food deserts are talked about: access, price, and quality (Gordon et al. 2011, Handbury et al. 2015, Ver Pleog et al. 2015, Haskell 2022). All three of these patterns appear in the U.S. Farm Bill definition for a food desert.

First, people who live in food deserts have a lack of access to nutritious food items, especially fresh produce. One factor is the total number of stores in a given area is small or the type of stores do not offer the foods needed for consumers. Grocery stores, supercenters, and big box stores, like Costco, are where consumers find fresh produce (fruits and vegetables). Walmart holds the largest market share for grocery sales with 26% (Benner et al.2020).

Poor infrastructure like lack of public transportation, broken roads and highways, lack of sidewalks, etc. is another factor in poor access for consumers (Dutko et al. 2012). In the USDA's National Household Food Acquisition and Purchase Survey (FoodAPS), where over 4,800 households were surveyed, 66% of food insecure households have their own vehicle, while it was 92% for food secure households. An USDA study from 2015 found that the average distance that a household, regardless of their subgroup, had to travel to a SNAP-authorized supermarket or supercenter was 2.19 miles. In addition, the household, on average, traveled 3.8 miles to reach their usual store of choice. For households that were SNAP participants, they had to travel 2 miles to the nearest SNAP-authorized supermarket and traveled 3.3 miles to their usual store. WIC-participants traveled at 1.77 miles and 3.1 miles, respectively (Ver Pleog et al. 2015).

A second pattern for food deserts is if the store is located in the area, then the food prices are out of a comfortable range for the local community. A food mirage describes this phenomenon of an area where nutritious food prices are not affordable by the local population (Haskell 2022). This can cause the local consumer to travel further for the prices they are willing to pay. Food leakage occurs when consumers seek their grocery shopping out of the neighborhood where they live (Faust & Esterline 2020). The third pattern for food deserts is the quality of food available. An area where an overrepresentation of convenience stores, dollar stores, and/or fast-food restaurants is referred to as a food swamp. Their presence tends to drown out the market share for traditional grocery stores (Faust & Esterline 2020,

Rose et al. 2009). An area, regardless of income level, can be classified as a food swamp, but a low-income area is more likely to have an overabundance of dollar stores, corner stores, and fast-food restaurants (Faust & Esterline 2020).

Five categories that can describe the issues within food deserts, which have some overlap with the earlier patterns of access, price, and quality. These categories are availability, accessibility, accommodation, affordability, and acceptability (Leroy et al. 2015). These terms are also referred to as the five dimensions of food access (Leroy et al. 2015).

Availability refers to the quantity of food available for purchase. For example, the total number of stores for a consumer to choose from. Accessibility is the distance between the consumer and food. The low-access aspect of the food desert definition falls under this variable. Acceptability is the awareness of the food consumers and producers. Accommodation is the ability to accept various payment methods like Supplemental Nutrition Assistance Program (SNAP), Electronic Benefit Transfer (EBT), credit card, cash, etc. Affordability is the food price relative to a consumer's income level.

In 2022, consumers are more comfortable with shopping outside the traditional brick-and-mortar stores because of the rise of Amazon. Starting in July 1995, Amazon sold books before expanding to other non-food items (Adkission, 2019). Later, Amazon added food as part of their delivery products with the acquisition of Whole Foods in 2017 (Adkission 2019, Petrom2021). Many large grocery chains and supercenters, like Kroger and Walmart, have added parking spaces near their locations reserved for online curbside pick-up. The traditional style of shopping will still dominate food sales as 61% of respondents in Nielsen survey enjoy the experience of shopping in a grocery store (The Nielsen Company 2015). However, e-commerce cannot be ignored. Social programs, like SNAP (Supplemental Nutrition Assistance Program) in 2019, have added an online payment option for better accommodation for SNAP participants.

Currently, e-commerce consumers purchase their food online and their options include picking-up their order in a mode of transportation of their choosing or having their order delivered to their preferred location. A few issues must be addressed regardless of what option the consumer chooses, like reliable high-speed internet access, the cost to own mobile device or computer, and the additional cost of using e-commerce services (membership fees, service fees, etc.). E-commerce allows consumers to buy anything online whenever and wherever they prefer, like at home, at work, at school, or while on-the-go. E-commerce also enables consumers flexibility in how their food arrives to their preferred location (residence, work, etc.) via delivery and curbside pick-up. Modern consumers have grown appreciation for the increased convenience and grown used to accelerated shipping like Amazon Prime's standard two-day shipping. A decade prior, two-day shipping was an expensive upcharge, regardless of the service. The radical change because of the Internet suggests the way food deserts are defined or discussed must change.

To use ecommerce services, a consumer must have a device capable of using the Internet, and Internet access from an Internet Service Provider (ISP). There is a difference in infrastructure between rural and urban areas. In 2018, 80% of the 24 million U.S. households without a broadband, non-mobile service provider lived in a rural area (A Case for Rural Broadband 2019). In relation to food desert and ecommerce, the name digital food desert was created to describe an area with limited access to online grocery because of infrastructure or an area's online grocery market resembles a physical food desert (Meslin 2018).

The shift towards using e-commerce for addressing food deserts has begun with the introduction to SNAP online. The SNAP Online Purchasing Pilot program, starting April 2019, allows SNAP participants to use their SNAP benefits to make food purchase online. The pilot program was mandated because of the 2014 Farm Bill (PL-113-79) (USDA, 2022). Eight retailers were part of the initial launch included Amazon, Dash's Market, Fresh Direct, Hy-Vee, Inc., Safeway, ShopRite, Walmart, and Wright's Markets, Inc.

The participating states in the pilot were Alabama, Iowa, Maryland, Nebraska, New Jersey, New Jersey, New York, Oregon, and Washington (USDA, 2022). The program has expanded to 38 states and the District of Columbia by June 2020. During that time, 90% of SNAP participants were estimated to live in those 38 states. By the end of 2020, the program expanded again to 47 states and the District of Columbia (Jones 2021). As of June 2021, Alaska, Louisiana, and Montana have not implemented the pilot program. However, the benefit cannot be used for delivery fees and other

additional fees charged by a private company as online transactions using SNAP benefits adhere to the same requirements as in-person purchases (Jones 2021).

In the 2010s, there has been an expansion in e-commerce in retail as well as food industries. So far, packaged foods that are non-perishable are more popular with online purchases (The Nielsen Company 2015). Fresh foods will be more challenging from a distribution standpoint and a consumer confidence standpoint. There is a sensory component to shopping for fresh fruit or baked bread that an online food order cannot compare to. (The Nielsen Company 2015). In addition to increasing access to traditional grocery stores, the inclusion of modern solutions, like online food subscription services, aid in reducing food deserts impacts on the population. Before the COVID-19 pandemic, only 2% of grocery sales were completed online. As of late 2020, that number has increased up to 10% of grocery sales are made online (Benner et al. 2020).

The consumers who use the Internet tend to be younger, highly educated, and have a higher income (Pew Research Center 2021). It is important to examine who are the current consumers in the e-commerce market. In a survey done by Nielsen in 2015, Generation Z (born between 1997 and 2012) and Millennials (born between 1981 and 1996) already utilize e-commerce solutions for their grocery shopping, 28% and 30% respectively. While another 55% and 57% respectively are willing to use e-commerce for their grocery shopping (The Nielsen Company 2015). For young generations like younger Millennials, Generation Z, and beyond, there was no time in their lives when the Internet did not exist. E-commerce solutions rely on the Internet as a fundamental aspect to work as designed. Generation X (born between 1965 and 1980) is not far behind Millennials in willingness to use and actual usage. However, Baby Boomers (born between 1946 and 1964) and the Silent Generation (born between 1928 and 1945) lagged far behind (The Nielsen Company 2015).

3. Methods

Lyft offered programs in collaboration with UNC Charlotte, Charlotte-Mecklenburg Food Policy Council, the city of Charlotte, Second Harvest Food Bank of Metrolina, and Loaves and Fishes to lower the cost of transportation to and from grocery stores and food pantries for eligible Charlotte consumers. The pilot program was executed from mid-2019 to early-2020 with 24 grocery locations available that included grocery stores, food pantries, and farmer’s markets. There were 75 participants, all 18+ years old, with smartphone access, an email address, and a bank card. Each participant received \$2 flat fee rides for up to 4 round trips per month. From the program’s intake survey, 56% of participants traveled to the grocery store a minimum of once per week. Their average time spent round trip in transit was 35 minutes (Mecklenburg County, n.d.). Based on the post-program’s findings, the average time from user’s ride request to destination was 17 minutes and the average subsidy was \$6.75 per ride after the flat fee. This program was also available in 12 other major North American cities like Atlanta, Baltimore, Toronto, and Washington, D.C. (Mecklenburg County, n.d.).

The food retailers in North Carolina that accept SNAP online payments are ALDI, Amazon, BJ’s Wholesale Club, Carlie C’s, Earth Fare, Food Lion, Publix, and Walmart (USDA, 2021). During February 2020, \$3 million in SNAP benefits or less than 0.1% of all SNAP benefits are from SNAP Online. By June 2020, this number expanded to \$154 million and to \$246 million by December 2020. (Jones, 2021). Factors like increased demand due to the COVID-19 pandemic and expanding the states included relate to the growth in the online benefits used. However, the redeemed online benefits in December 2020 made up 3% of the total SNAP benefits used (Jones 2021).

To better understand how e commerce works as a solution to address food deserts, we use visualization, a powerful method in communicating enormous amounts of information for a complex problem to others. Tableau and Policy Map were used to prepare data, analyze data, and create visualizations.

3.1 Data Collection

Table 1 contains data sources to investigate food deserts in Mecklenburg County via the four of the five 5As or five dimensions of food access.

Table 1. Data Sources

Type of Data	Location	Measure
Store Names	Google Maps, Policy Map	Store Name
Store Address	Google Maps, Policy Map	Address Format

Store Location	Google Maps, Policy Map	(Geodata/GIS Data)
Delivery Price	Individual Websites for Service – Walmart.com, Instacart, etc.	Dollars (USD)
Cost of Driving a Car per Mile	AAA/IRS (Internal Revenue Service) - https://newsroom.aaa.com/wp-content/uploads/2021/08/2021-YDC-Brochure-Live.pdf	Dollars (USD)/mile
Food desert location	Census Website - https://data.census.gov/cedsci/table	Binary (Y/N or 1/0)
Food insecurity %		Percentage
Census Tract Location		Location (Geodata/GIS Data)
Internet Speeds in Mecklenburg County	BroadbandNow.com	Mbps (Megabits per second)
ISPs in Mecklenburg County	BroadbandNow.com	# of providers, provider names
Cost of Internet Access in Mecklenburg County	BroadbandNow.com	Dollars (USD)
SNAP Online Benefits (store that accept benefits)	USDA Website - https://www.fns.usda.gov/snap/online-purchasing-pilot	Stores names
Online Services (Pick-up or Delivery)	Specific Store Website – Walmart.com, Adli.com, etc.	Binary (Y/N or 1/0)

3.3 Visualization Development

The e-commerce solution for Mecklenburg County’s food desert was evaluated via four of the five dimensions, availability, accommodation, accessibility, and affordability. Each dimension was represented by a visualization. Acceptability, which was left out of the analysis, required evaluating information available for consumers and retailers, and conducting surveys on online food service effectiveness, which is out of this project’s scope. Examining acceptability can be a future project on its own. The remaining dimensions of food access were then evaluated. The Mecklenburg County-based study focused on the number of ecommerce solutions available, the total ecommerce costs to the consumer, the current level of Internet access, and if SNAP benefits were accepted.

Availability and accommodation: For the dimensions of availability and accommodation, a visualization was developed for the Mecklenburg County that consist of: the food desert definition of the required low-income population and 0.5 mile low-access for urban areas and 10 mile low-access for rural areas; census tract demographic information; pinned for store geographic (GIS) locations that offer online food services via in-store pick-up, curbside pick-up, and delivery options; an overlay using the 1 mile urban, and 10-mile rural access criteria was also created. Every store location in Mecklenburg County, limited to supercenters (Walmart, Target), supermarkets (Kroger, Harris Teeter), big box stores (Costco, Sam’s Club), and grocery stores (Aldi) were listed for this analysis. All these stores offered fresh produce, meats products, dairy products along with non-perishable food items. The information compiled for each GIS store location included the store’s address, what census tract it was located in, if it was SNAP and SNAP Online acceptable, and if food delivery or pick-up was offered with an online food service.

No online-only services like Hello Fresh, NutrientSystem, and Blue Apron, were included since they were available to any address that United States Postal Service (USPS), UPS, or FedEx delivers to. Online-only services can be its own study as it would involve an examination of the access to delivery, especially in rural areas, and Internet access

(speed and coverage). Convenience stores and dollar stores were not considered either as they normally do not offer online food services. Values stores and pharmacies like CVS and Walgreens were not included.

Using the GIS locations, the available e-commerce solutions within Mecklenburg County census tracts were compared to each other. An index was made of the total number of e-commerce solutions within a census tract compared to the average number of e-commerce solutions across all census tracts within Mecklenburg County. A min-max feature scaling was applied so that the scale ranges from 0 (lowest number of available solutions within a tract) to 1 (highest number of available solutions within a tract).

$$I_i = \frac{e_i - e_{\min}}{e_{\max} - e_{\min}} \dots\dots\dots(1)$$

where

I_i is the scale for a census tract i

e_i = # of available ecommerce solutions within census tract i

e_{\max} = maximum # of available solutions within any Mecklenburg County census tract

e_{\min} = minimum # of available solutions within any Mecklenburg County census tract

For example, if a given census tract called ‘A’ had 3 e-commerce solutions, the maximum number of solutions across any census tract was also 3, and the min. number was 0, then the scale for census tract ‘A’ would be 1. Or if the available solutions within census tract ‘A’ was 1 and the maximum and minimum solutions remained fixed, then the index was 0.333.

$$I_A = \frac{1-0}{3-0} = 0.333 \dots\dots\dots(2)$$

From this, a visual comparison was made via an overlay on a Mecklenburg County map, which would give a detailed and nuanced look at food access in Mecklenburg County.

Accessibility: For the dimension of accessibility, a series of bar charts visualized the options for Internet access in Mecklenburg County based on the Internet Service Providers (ISPs). Without Internet access, a consumer cannot effectively use e-commerce solutions. The top ISPs, their monthly internet pricing, and the advertised Internet speeds were compared. Then, an investigation on how the ISPs report their advertised coverage was done.

Affordability: For the dimension of affordability, the cost of delivery (Walmart and Instacart) versus the cost of pick-up (personal vehicle and private transportation services, Instacart only) was visualized with a map overlay. A random sample of 25 (out of 233) Mecklenburg County census tracts was selected for evaluation. Each census tract was assigned a number from 1 to 233, and the random number function in Microsoft Excel was used to select the tracts. Then, the total monthly cost of ordering an item from an online food service within each selected census tract C_t , excluding the food item cost, was calculated. This monthly cost included the cost of Internet access, the cost of purchasing a mobile device, the cost of the e-commerce solution used, and the transportation costs. If the selected tract did not contain a solution within its boundaries, then the nearest solutions was used to calculate transportation costs.

- Monthly Internet access cost (\$/month) - C_I
- Monthly mobile device cost (\$/month) - C_m
- Monthly ecommerce service cost (\$/month) - C_e
- Monthly transportation costs (\$/month) - C_{tr}
- Per Order Service Charge (\$/order) - C_o
- Mobile device cost (\$) T_m
- Time (months) m
- Driving Distance to Nearest Store (miles) D
- Cost to drive car per mile (\$/mile) G_t
- Grocery store trips per week (orders/week) T

$$C_t = C_I + C_m + C_e + C_{tr} \dots\dots\dots(3)$$

$$\text{For Subscription service \& Pick-up Option } C_t = C_I + \frac{T_m}{m} + C_e + (2 * D * G_t * T * \frac{52 \text{ weeks}}{12 \text{ months}}) \dots\dots\dots(4)$$

$$\text{For Per Order \& Pick-up Option } C_t = C_I + \frac{T_m}{m} + (C_o * T * \frac{52 \text{ weeks}}{12 \text{ months}}) + (2 * D * G_t * T * \frac{52 \text{ weeks}}{12 \text{ months}}) \dots\dots\dots(5)$$

For Subscription service & Delivery Option $C_t = C_l + \frac{T_m}{m} + C_e$(6)

For Per Order & Delivery Option $C_t = C_l + \frac{T_m}{m} + (C_o * T * \frac{52 \text{ weeks}}{12 \text{ months}})$(7)

In this research, we assume:

$C_l = \$110 \text{ per month}, T_m = \$550, m = 24 \text{ months}$

$G_t = \$0.637 \text{ per mile for personal car}; \$2.50 + \$1 \text{ per mile for Lyft}$

$T = 1.6 \text{ shopping trips per week}; \text{order size greater than } \35

There was a set of assumptions made to calculate the monthly cost to use ecommerce food services. These assumptions simplified the calculations. The median monthly cost for the Internet in Mecklenburg County was about \$110 per month. The average price for a mobile device (cell phone) that a consumer would use was \$550. Since this was a one-time purchase price, the monthly cost was calculated by dividing the device cost by a standard two-year (24 months) contract for a mobile device. For this calculation, the entire cost of Internet and mobile device assumed to only be used for ordering online food orders. In reality, the cost of Internet and mobile devices would be split across multiple purposes, like phone calls, email, video streaming, etc.

According to the American Automobile Association, in 2020, the average cost to drive a private car was \$0.637 per mile at 15,000 miles per year, when including the cost of the car itself, insurance, gas, maintenance, tags and registration (American Automobile Association, 2020). Lyft cost an estimated \$1 per mile plus a \$2.50 base fee. The Lyft rate varies from city to city, the time of day, and local demand for transportation, so this estimate is on the conservative side. From a 2019 survey, the average weekly grocery store trips per U.S. household is 1.6 and this will be used in the analysis (Tighe 2020).

Both Walmart and Instacart offer ordering without enrolling in their subscription service. Walmart charged nothing when the order was over \$35 and \$5.99 per order when the order was under \$35 (Walmart, 2021). Instacart, on the other hand, charged \$3.99 regardless of the order total plus a 5% service fee. For Instacart subscription users the service was reduced to 1.9% (Shoemaker, 2020). To simplify this calculation, the order size was assumed to be greater than \$35 regardless of if the consumer used the subscription service or not. When a consumer used the subscription services, Walmart Plus or Instacart Plus, the consumer paid a monthly fee for unlimited food orders and delivery.

$C_e = \$12.95 \text{ per month for Walmart Plus}; = 9.99 \text{ per month for Instacart Plus}$

$C_o = \$0 \text{ for Walmart order over } \$35; = \$ 3.99 + 5\% \text{ of total for Instacart order}$

Driving distance D will be found by using a census tract’s centroid geographic location, sourced from the US Census Bureau, and the nearest store’s location, find the distance a consumer must drive between those two points on a public road. This was completed using google maps.

4. Results and Discussion

4.1 Availability

A map overlay of Mecklenburg was made in Policy Map with GIS locations for stores and highlighted food desert tracts. In figure 1, the map included the boundaries of the county and census tracts, and path of major roadways. 95 grocery store locations were founded within Mecklenburg County. All stores accepted SNAP within the store and 86 of those stores accepted SNAP online payments. The 15 grocery store brands available within Mecklenburg County were: Aldi, BJ’s Wholesale Club, Costco, Food Lion, Lowes Food, Publix, Sam’s Club, Sprouts Farmer Market, Super G Mart, Target, The Fresh Market, Trader Joe’s, Walmart, and Whole Foods.

From a glance at Figure 1, many southern Mecklenburg County census tracts contained an ecommerce solution that offered online pick-up within its boundaries. Store locations also aligned close to the three federal highways I-485 Inner and Outer Loop, I-77, and I-85 and a single U.S. highway US-74, which meant easier access for a consumer driving their own car or using a private transportation service like Uber or Lyft. The store locations appear to group together while the census tracts without a location also clustered together. 164 census tracts out of 233 contained no solutions (pick-up or delivery) and had an availability index of zero. One solution within the census tract was the next most common occurrence at 50 census tracts.

26 store locations did not offer online delivery from that location and 7 store locations offered neither a delivery nor curbside pick-up option. For example, no Trader Joe's store offered pick-up or delivery options. 6 Harris Teeters and 11 Food Lions did not offer delivery, yet they offered curbside pick-up. However, in-store pick-up was always available for stores that offer online purchases.

For online delivery, since the cost to the consumer was the same regardless of distance to store, the number of available solutions was examined. West Charlotte and east Charlotte had severe reductions in available solutions for food delivery. These consumers still could order from other sections of Mecklenburg County, but their food order must travel a further distance to reach them, which can affect the timetable for an order. Southern Charlotte and Pineville continued to have available delivery options available despite the decrease. Northern Mecklenburg County had minor changes to its offering. The light red (pink) dots in Figure 2 represented the store locations with no online delivery. Figure 2 shows a map overlay with the color-coded availability index and GIS store locations. The maximum number of solutions within a census tract was 3, while the minimum amount was 0. See table 2 for conversion from number of solutions to availability index used in Figure 2.

4.2 Accessibility

For accessibility, a consumer must have reliable Internet. When examining the internet service providers (ISP) in Mecklenburg County, Spectrum, Viasat and HughesNet advertised 100% internet coverage. AT&T and EarthLink claim 88.2% and 82.3%, respectively. Figure 3 shows the top 11 ISPs by Internet Coverage.

From an initial glance, Mecklenburg County had high Internet coverage. However, the method in how ISPs report their Internet coverage to the federal government is flawed. Currently, ISPs report their internet coverage and speed data to the Federal Communications Commission (FCC) via Form 477 twice a year. If at least one address inside a census block can receive 200 kilobits per second (kbps) in one direction within 10 days, the census block was classified as covered for Internet (National Broadband Map 2021). There were many limitations to this approach.

The first limitation was that internet speed was only required to be reported in one direction (upload or download) and not both. Download speeds are more important to consumers. This is evident because the FCC changed their classification for broadband service as 25 Mbps download speed and 3 Mbps upload speed in 2015 (National Broadband Map 2021). The 200-kbps requirement for Form 477 does not meet what the FCC classifies as broadband service. Even if the ISPs did push their required Internet speeds to an area, the consumer might receive a fraction of the advertised speeds because of poor infrastructure like overhead Internet lines versus buried Internet lines or a lack of fiber optics lines.

The FCC started to move away from ISP reporting and crowdsource the internet from consumers themselves. Consumers can self-report data on who was their ISP, the actual Internet speed they received, their address type (residential, business, etc.), and type of Internet infrastructure (fiber optics, cable, etc.). This newer approach is labor intensive but provides a more accurate picture on Internet accessibility. The North Carolina Department of Information Technology (NCDIT) gathers self-reporting data, where there were 766 data points on Internet service throughout Mecklenburg County and 55 points had no Internet access (Broadband Survey Data 2022).

Another limitation was that a census block contained many addresses and requiring at least one address with service did not truly represent that an area had accessible Internet service. A third limitation was an ISP can report that they could provide service within the 10-day window, but not if they actually did provide the service.

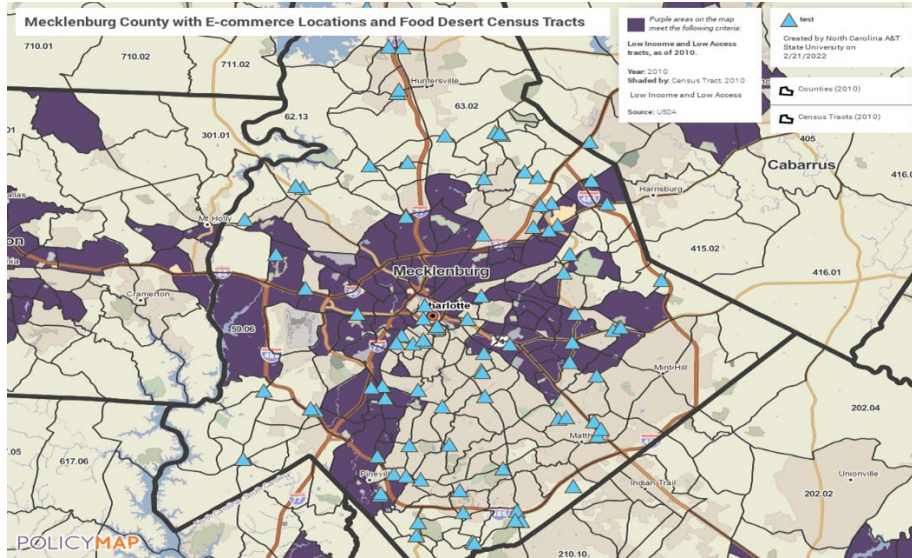


Figure 1. Mecklenburg County with food desert status highlighted per census tract and geographic store locations.
Made by Policy Map

Table 2 . Solutions within a Tract vs. Availability Index and Census Tract Totals

Number of Solutions in Tract	Index Number	Number of Tracts
0	0	164
1	0.333	50
2	0.667	18
3	1	1

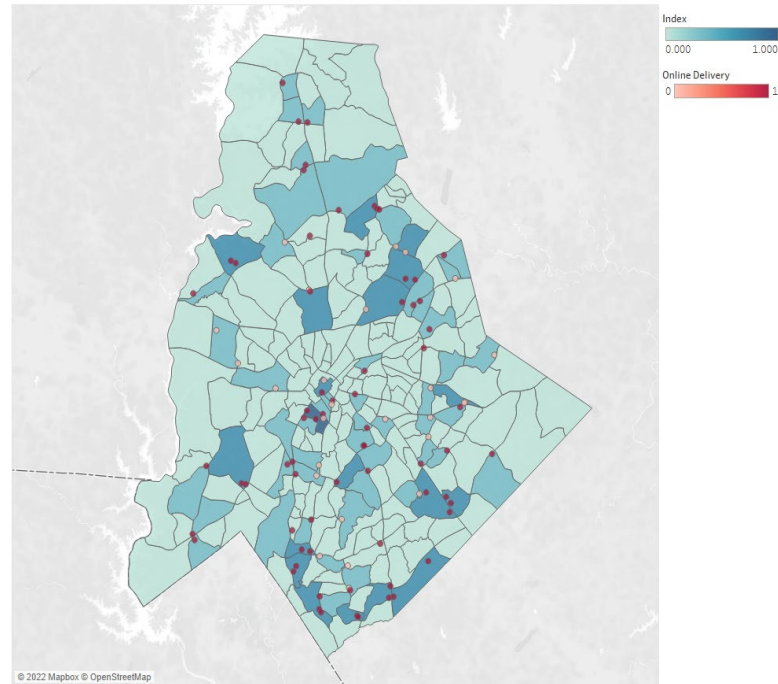


Figure 2. Mecklenburg County with food desert status highlighted per census tract, availability index, and geographic store locations. Red Dot = Online Delivery, Pink Dot = No Online Delivery

4.3 Affordability

Of the 25 randomly selected census tracts, the maximum number of available solutions within a single census tract was three, while zero was the minimum available solution. Eight of the census tracts contained at least one solution. Figure 4 visualizes the selected census tract and their availability index. For instance, the monthly delivery cost for both Walmart and Instacart was stable at \$141.10 and \$142.90 respectively, because the delivery options' cost was not dependent on distance between store location and a consumer's address. Instead, the additional cost came from the number of orders placed monthly. Since both services offered subscriptions, where unlimited deliveries were available, ordering delivery via the subscription service was the most cost-effective option. Instacart, while the more flexible option with many store offerings including Walmart too, costs more for both delivery and pick-up. On a per order basis, Instacart charged an additional service fee per order at 5% of the order total for non-subscription users and 1.9% for subscription users.

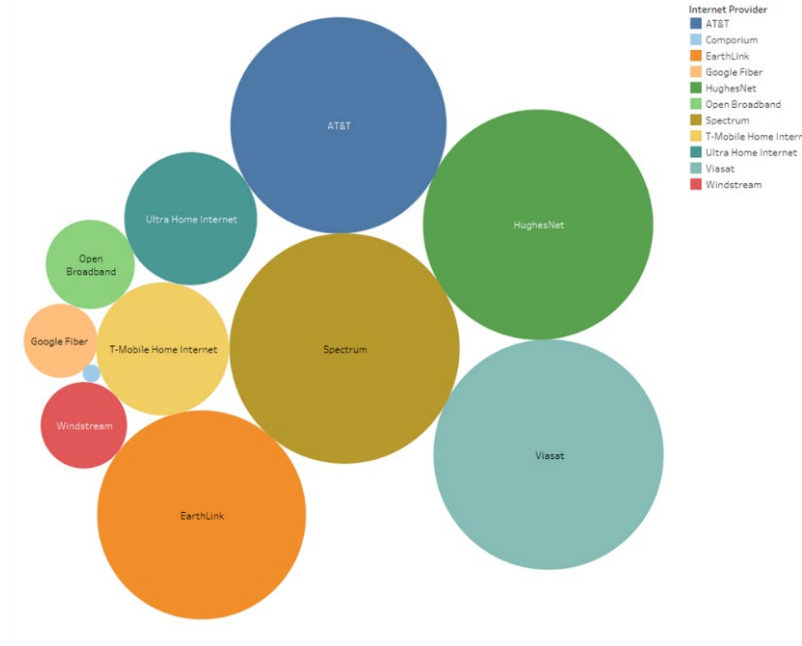


Figure 3. Top 11 Internet Service Providers in Mecklenburg County, in terms of Internet coverage

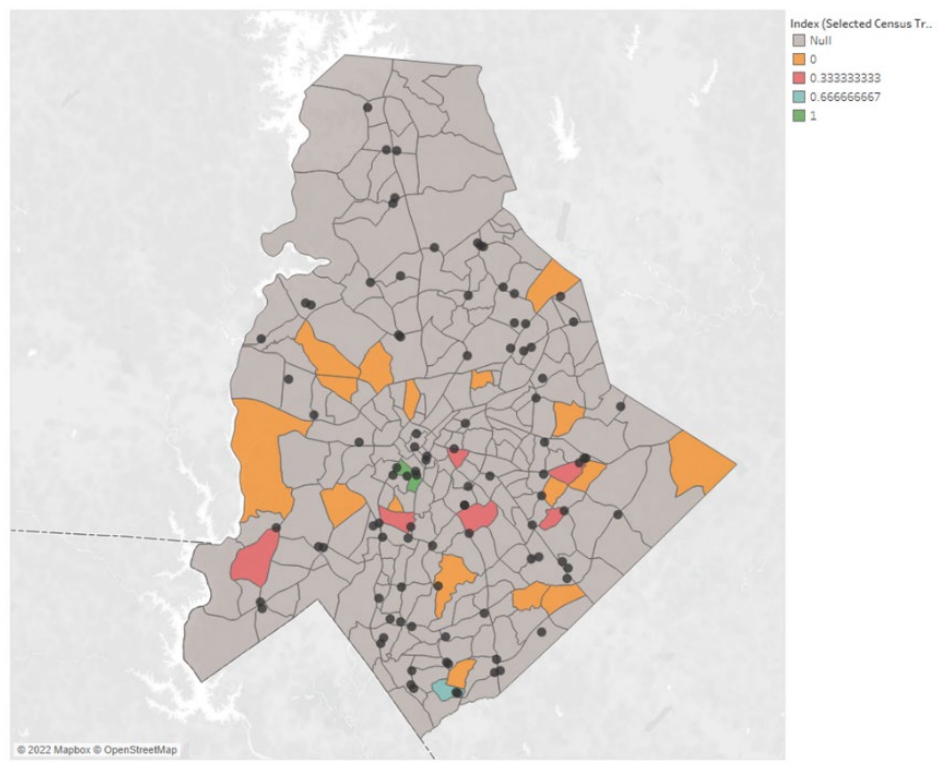


Figure 4. Mecklenburg County with randomly selected census tracts with availability Index

For pick-up option, a consumer driving their own car was more cost-effective than Lyft by a median of \$13.07 per month across the randomly selected census tracts. The cost for a consumer to drive their own car is about 0.637 cents per mile, if they drive 15,000 miles a year (2020-Your-Driving-Costs, 2020). This included the cost of a car, the insurance, fuel costs, maintenance costs, tags, and registration. With an Instacart subscription service, the median monthly cost for driving their own car for pick-up option was \$157.34 and for using Lyft for transportation was \$169.54, as seen in figures 5 (a) and 5(c).

The median driving distance from the census tract centroid to the nearest store location was 2.1 miles as seen in figure 5(b). In a 2015 USDA study, the findings were that average distance from a household to a SNAP-authorized supermarket of supercenter is 2.19 miles (Ver Pleog et al., 2015).

As seen in figures 5(a) and 5(c), Census tract 57.15, the most eastern Mecklenburg County census tract, was the outlier at \$199 and 233 monthly costs, respectively, when staying within the boundary of Mecklenburg County for a store location. This census tract also had the highest driving distance from a store location at 6.7 miles, seen in figure 5(b).

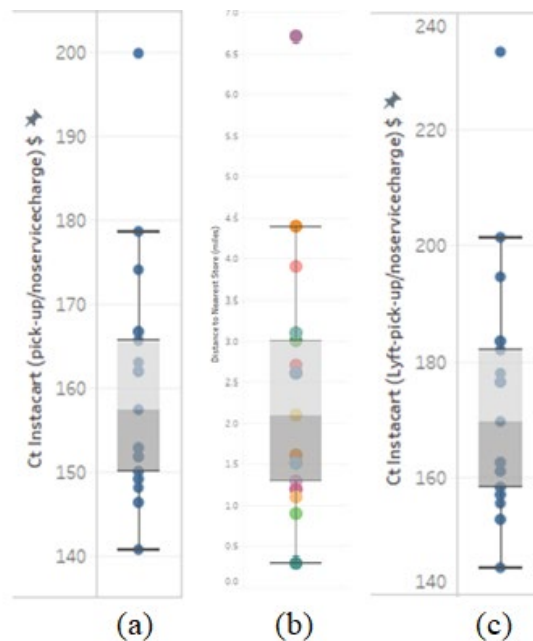


Figure 5. (a) Monthly Cost for Instacart with Instacart plus subscription and pick-up with personal car
(b) Driving Distance to nearest store location for randomly selected census tracts
(c) Monthly Cost for Instacart with Instacart plus subscription and Lyft pick-up

5. Discussion

From this study, Mecklenburg County was examined for its e-commerce solutions and the current e-commerce solutions addressing food deserts. Many of the census tracts in Mecklenburg County were urban tracts, due to the city of Charlotte dominating the land area within the county. All food deserts were urban tracts. These food deserts were concentrated around downtown Charlotte in a C shaped cluster. With the exception to one census tract, every food desert census tract shared a border with another food desert census tract. Store locations also grouped together near major roadways, which allowed easy vehicle access for consumers and retailers. However, a section of Interstate 85 that ran through a group of food deserts census tracts did not have store locations near it. A potential study could examine if food deserts cluster together and the reasons why.

Limitations in Internet coverage reporting across the U.S. was not accurate to what consumer experienced. Current reporting to the FCC via Form 477 had vague language to allow inaccurate data from ISPs. When looking at 2021 self-reporting from the NCDIT, 7% of cases (out of 766 reports) experienced a lack of Internet coverage in

Mecklenburg County. Since Mecklenburg County included mostly urban tracts the Internet infrastructure would be better than a county with more rural tracts.

With ecommerce, consumers must consider additional costs like delivery and service fees along with their transportation costs and Internet bill. In total to use ecommerce in Mecklenburg County the consumer paid between \$140 to \$200 per month, depending on their situation. None of these costs could be covered by SNAP benefits. A way to reduce a consumer's cost and increase usage of ecommerce services would be to add a monetary reserve in SNAP benefits specific to covering delivery and service fees. In addition, the government could make a policy which restricts the charges a SNAP participant is charged in fees. Delivery costs for food retailers depended on many factors, like demand density, proximity to intended delivery area and multitasking for delivery trucks. Delivery costs for a consumer were stable across Mecklenburg County census tracts because the burden of cost was on the food retailer. On the other hand, pick-up costs were not stable since a consumer had to travel a longer distance to reach their nearest store location. A consumer using their personal vehicle for pick-up was cheaper than using private transportation like Lyft. There are many routes to branch out in the research of food deserts and ecommerce. One potential study is an investigation in the Internet infrastructure and available food services in rural areas. Both factors, suggested by multiple studies, may indicate an underlying issue with the investing and policy for rural areas (USDA, 2019, Newing, 2021). This study can properly define what acceptable Internet infrastructure is, like Internet speeds, Internet coverage, number of ISPs available, the type of equipment used to deliver Internet services, etc.

Another investigation can be into the digital food desert, a local online market that mimics the conditions of a physical food desert and with poor Internet infrastructure. Like the previous future study mentioned, poor Internet infrastructure needs a more concrete definition. A question could be if this online market extends to convenience stores because they have moved toward online services and delivery. For example, CVS, Walgreens, and Dollar General all offer online shopping. Would there be such a case as a digital food swamp? Consumers have sensory and trust issues with purchasing fresh foods online. How does advertisement of unhealthy foods factor into these decisions?

One last future study is investigating the scenarios that fluctuate the costs for consumers to use ecommerce services. The results of \$140 to 200 for monthly cost in Mecklenburg County make a lot of assumptions. For example, the cost to operate a personal vehicle differs based on total miles driven per year, which the more miles driven, the cheaper per mile drive is. Certain cars cost more than others to operate because of differences in fuel costs, insurance costs, and maintenance costs. If a consumer uses Lyft for their transportation to pick up their food order, then they must consider price variations because of geographic location, current demand, number of available vehicles, etc. Another assumption is the number of orders per month is the same. How does a consumer's order frequency change based on the time of year? What if a consumer orders more food during the summer when fuel costs are higher? One last assumption was ordering online food order assumed the total cost of Internet and mobile device. However, a consumer uses the Internet and their mobile device for multiple purposes and a future study would take this into account.

Acknowledgements

This research is partially funded by the National Science Foundation award # 260303 and award #2100855. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

- Adkisson, K. The Emergence of Ecommerce into the Grocery Industry: A Case Study of Amazon's Acquisition of Whole Foods Market and Its Effects on Consumer Behavior (Unpublished master's thesis). University of Oregon, 2019.
- Benner, C., Mason S., Carré, F., &Tilly, C. *Delivering Insecurity: E-commerce and the Future of Work in Food Retail*. Berkeley: UC Berkeley Labor Center and Working Partnerships USA,2020.
- Broadband Survey Data (General, Phone, and Farm). Available: <https://experience.arcgis.com/experience/4096f70b64474e85a6646969902e514d> Accessed on July 12, 2022
- Dutko, P., Ver Ploeg, M., & Farrigan, T. . *Characteristics and Influential Factors of Food Deserts* (Economic Research Report, pp. 1-30, Rep. No. 140). United States Department of Agriculture, 2012.
- Faust, C., & Esterline, A. *A Visual Analysis of Food Availability in Davidson County NC*. IEEE Southeast Conference, 2020.

- Gordon, C., Purciel-Hill, M., Ghai, N. R., Kaufman, L., Graham, R., & Van Wye, G. . Measuring food deserts in New York City's low-income neighborhoods. *Health & Place*, 17(2), 696-700, 2011. doi:10.1016/j.healthplace.2010.12.012
- Handbury, J., Rahkovsky, I., & Schnell, M. . *Is the Focus on Food Deserts Fruitless? Retail and Food Purchases Across The Socioeconomic Spectrum*. National Bureau of Economic Research, Cambridge, 2015.
- Harris, G., & Boger, M. .*Food Deserts*. Charlotte: Mecklenburg County Health Department, 2020.
- Haskell, S. Food insecurity and food deserts: How are they related? Available: <https://www.canr.msu.edu/news/food-insecurity-and-food-deserts-how-are-they-related> Accessed on February 03, 2022
- Institute of Medicine (IOM) & National Research Council (NRC). *The public health effects of food deserts: Workshop summary*. Washington, DC: The National Academies Press, 2009.
- Jones, J. W. . Online supplemental nutrition assistance program (SNAP) purchasing grew substantially in 2020. July, 2021. Available: <https://www.ers.usda.gov/amber-waves/2021/july/online-supplemental-nutrition-assistance-program-snap-purchasing-grew-substantially-in-2020/> Access on February 05, 2022,
- Kerrick, B., Spitzer, T., Brighton, E., Hishaw, J., & Caldwell, L. *Unlocking The Potential of Charlotte's Food System and Farmers' Market*, July, 2018. Available: https://charlottenc.gov/HNS/CE/Documents/KKP_CharlotteFarmersMarketsFINAL.pdf, Accessed on January 10, 2022
- Leroy, J. L., Ruel, M., Frongillo, E. A., Harris, J., & Ballard, T. J. Measuring the food access dimension of food security. *Food and Nutrition Bulletin*, 36(2), 167-195, 2015. doi:10.1177/0379572115587274
- Mecklenburg Country. Healthy Corner stores. Available: <https://www.mecknc.gov/HealthDepartment/CommunityHealthServices/FoodSecurity/Pages/HealthyCornerStores.aspx> Access on January 10, 2022
- Meslin, H. R. Food Access in the Age of Online Grocery: An Evaluation of Current Retail Trends and Their Potential to Alleviate Food Deserts in the U.S. *IU Journal of Undergraduate Research*, 4(1), 58–62, 2018. <https://doi.org/10.14434/iujur.v4i1.24379>
- Newing, A., Hood, N., Videira, F., & Lewis, J. ‘Sorry we do not deliver to your area’: Geographical inequalities in online groceries provision. *The International Review of Retail, Distribution and Consumer Research*, 32(1), 80-99, 2021. doi:10.1080/09593969.2021.2017321
- Nielsen Global E-commerce New Retail Report April 2015. (2015, April). New York City: The Nielsen Company LLC.
- Pew Research Center. Demographics of internet and home broadband usage in the United States. November 23,2021. Available: <https://www.pewresearch.org/internet/fact-sheet/internet-broadband/?menuItem=9a15d0d3-3bff-4e9e-a329-6e328bc7bcce> Access on January 10, 2022
- Tighe, D. Weekly number of U.S. grocery shopping trips per household 2019. November 27, 2020. Available: <https://www.statista.com/statistics/251728/weekly-number-of-us-grocery-shopping-trips-per-household/#statisticContainer> Access on April 1, 2022.
- USDA, *A Case for Rural Broadband: Insights on Rural Broadband Infrastructure and Next Generation Precision Agriculture Technologies*. 2019. Published as part of American Broadband Initiative.
- USDA Economic Research Service, Definitions of Food Insecurity; updated 2017 Nov 27. Available: <https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-us/definitions-of-food-security/> Accessed on January 16, 2021
- USDA, SNAP Online Purchase Pilot, Available: <https://www.fns.usda.gov/snap/online-purchasing-pilot>, Accessed on September 10, 2022
- USDA, Food access research atlas, Available: <https://www.ers.usda.gov/data-products/food-access-research-atlas/documentation/>, Accessed on April 5th, 2023
- Ver Ploeg, M., Nulph, D., & Williams, R.. Mapping food deserts in the United States. *Amber Waves: The Economics of Food, Farming, Natural Resources, and Rural America*, 4, 2011
- Ver Ploeg, M., Mancino, L., Todd J., Clay D.M., & Scharadin, B. Where Do Americans Usually Shop for Food and How Do They Travel to Get There? Initial Findings From the National Household Food Acquisition and Purchase Survey, EIB-138, U.S. Department of Agriculture, Economic Research Service, March 2015.

Biographies

H. Washington is an MS student in the department of Industrial and Systems Engineering at North Carolina A&T State University. He graduated from the University of Maryland, Baltimore County in 2011 with a bachelor's degree in mechanical engineering. In between pursuing his education for 8 years, he has worked in the Metrology and Lighting industries, specializing in electro-mechanical product design, documentation, and process improvements.

S. Jiang is an Associate Professor in the department of Industrial and Systems Engineering at North Carolina A&T State University. His main research areas are human systems integration and visual analytics.

L. Davis is a Full Professor in the department of Industrial and Systems Engineering at North Carolina A&T State University. Her research interests include supply chain and optimization.

H. Kim is an Assistant Professor in the department of Industrial and Systems Engineering at North Carolina A&T State University. His research interests include human computer interaction and human factors in healthcare.