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Measuring Food Access to Improve Public Health

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Food access is important due to its impact on public health outcomes. A food access metric proposed for four different transportation modes is the square footage of supermarkets that can be reached within 10 minutes travel time walking, biking, driving, and 30 minutes travel time by walk/transit. The spatial analysis is conducted for the centroids of each census tract within a study area. An equity analysis using Lorenz curves shows that food access is most equitable by driving, and there are significant inequities for people that do not have access to a car. A regression analysis using the gradient boosted model, a machine learning method, shows gaps in food access for each transportation mode while controlling for community characteristics. The residuals of the model reveal which communities have the lowest food access relative to other similar communities within the state. The results reveal food access gaps in urban, suburban, and rural communities. Finally, focus groups with representatives of community organizations reveal the complex ways that transportation and socioeconomic factors interact to affect food accessibility. This research provides a quantitative method to identify gaps in food access and insights for where policy interventions would be valuable for improving food access.

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Measuring Food Access to Improve Public Health

Final Report

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Disclaimer

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Executive Summary

This study of Measuring Food Access to Improve Health, was undertaken as part of the Massachusetts Department of Transportation Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

The degree to which people physically have access to various kinds of destinations significantly affects well-being; for example, access to not only jobs and education but, access to health care, food, and recreational activities each directly affect health outcomes. The goal of this project is to document metrics and methodologies used to assess accessibility and correlate them with other socioeconomic and demographic characteristics to assess inequities associated with the lack of accessibility that often leads to health disparities. The specific focus of this study is on food accessibility—namely, how to measure food accessibility, how to analyze it to identify food access gaps, and how to improve access to food. This work is intended to provide a data-based view of food access across Massachusetts using available statewide data sources and to make recommendations for how food access should be measured and considered in making policy decisions and transportation investments.

The goal of this project is to document metrics and methodologies used to assess accessibility and inequities with a particular focus on access to food. Food accessibility is critical for a community's health, because the food environment can either promote or discourage a healthy diet depending on the variety of products that are available. This report presents a method to identify communities that lack access to food and understand the connection between socioeconomic variables and food accessibility. A spatial analysis and a variety of regression models using machine learning methods are proposed to quantitatively compare food accessibility in communities across Massachusetts. The results were shared with stakeholders from specific communities which the data suggests present food access gaps. Once selected, local stakeholders were engaged through focus group discussions in order to understand the context of food insecurity and food accessibility, especially in suburban and rural communities. Finally, recommendations are made, based on the quantitative analysis and the focus group discussions, for actions that can be taken to improve food access in Massachusetts and elsewhere.

Measuring Food Accessibility

One contribution of this study is a proposed metric for food accessibility from a given location based on the square footage of food retailer space that can be reached within a travel time budget. Conventional measures of food accessibility focus on simple counts of stores that can be reached within a certain distance, as the crow flies. We propose to measure the square footage of supermarkets that can be reached within a certain travel time, because this is more likely to reflect the breadth of food choices available to an individual. The travel time constraint is also important because it represents the time a person actually spends traveling on the network. This method for quantifying food accessibility also has the benefit that it can be used to distinguish between accessibility by different transportation modes. In this report, comparisons are made between walking, bicycling, a combination of walking and transit, and driving.

Data sources used for the analysis in this study include a data set containing the following information for 1,801 supermarkets across Massachusetts:

- Street address,
- Latitude/longitude, and
- Store size (square footage).

This data is supplemented by the following types of demographic data for each of the 1,472 census tracts in Massachusetts:

- Population density,
- Vehicle ownership per person,
- Percent of population in poverty, and
- Percent of population identifying as racial or ethnic minority.

A spatial analysis uses these data along with an analysis tool called Conveyal to compute the food accessibility for each census tract in Massachusetts for travel time constraints of 10 minutes walking, 30 minutes walk/transit, 10 minutes bicycling, and 10 minutes driving.

The analysis shows that food accessibility by driving is significantly greater across the state than by other modes, indicating that households without access to a car are at a distinct disadvantage in terms of food access. Furthermore, an equity analysis shows that food accessibility is less equitably distributed for nondriving modes, with nearly 2/3 of the Massachusetts census tracts exhibiting no access to food within 10 minutes walking.

Finally, a machine learning method called a gradient boosted model (GBM) is used to identify the relationship between socioeconomic characteristics of census tracts and the measured food accessibility. The models show that population density and vehicle ownership are the most important determinates of food access. An important feature of the GBM method is that it can be used to identify communities which have low food accessibility relative to other similar communities. The analysis of model residuals shows that even when accounting for socioeconomic characteristics of communities, gaps in food accessibility exist across Massachusetts. Without a model, rural areas always have lower measured food accessibility than urban areas. With the model it is possible to tell which rural areas, suburban areas, and urban areas are lacking in food accessibility and in need of attention.

Focus Groups

To supplement the findings from the analysis of Massachusetts statewide data, this study included outreach to stakeholders in target communities. The goal of the stakeholder engagement was to compare the results of quantitative analysis on food access to the live experiences of stakeholders familiar with the unique barriers to food access within each specific community. The list of communities with low spatial food accessibility was overlayed with environmental justice plus (REJ+) communities, as defined by MassDOT, to identify communities of concern from a food access perspective. From this list, Deerfield was identified as a rural community with a food access gap, and Amherst was identified as a more suburban community with a food access gap. Separate focus groups were held online for each community, with invited attendees representing relevant stakeholder organizations such as regional transit agencies, Mass in Motion coordinators, councils on aging/senior centers, and food pantries/food charities. Worcester was identified as an urban community with certain census tracts lacking access to food, but due to logistic issues a focus group was not able to be organized within the city. The outcome of the focus groups was confirmation that the quantitative analysis made sense and a wealth of comments about the ways in which transportation and spatial mismatch pose barriers to food access for people in those communities.

Recommendations

From the analysis of food and demographic data, supplemented by the insights shared during the focus groups with stakeholders, several recommendations are made for ways to address food access in Massachusetts. These recommendations are organized in four general categories:

1. Measuring Statewide Food Access
    - Recommendation 1: Measure food access in a census tract by travel time constraint
    - Recommendation 2: Measure average statewide food access
    - Recommendation 3: Use a Gini coefficient as an indicator of food access equity
    - Recommendation 4: Coordinate with other efforts measure and analyze food access

2. Moving Food to People
    - Recommendation 5: Coordinate with municipalities and regional planning agencies to:
        a. Analyze candidate locations for new supermarkets in underserved communities.
        b. Identify locations that may be candidates for pilot projects that involve delivering fresh/healthy foods to smaller stores.
        c. Identify locations that may be good candidates for establishing mobile or pop-up food pantries.
        d. Identify locations where the direct delivery of food to households should be prioritized.

3. Moving People to Food
    - Recommendation 6: Expand transit services in communities with low food access, especially by the following strategies:
        a. Extend hours of transit operation,
        b. Extend/redesign transit routes, and
        c. Expand microtransit services.
    - Recommendation 7: Include data on food access in the evaluation criteria for the MassDOT Community Transit Grant Program.

- Recommendation 8: Improve integration/coordination between transit agencies.
- Recommendation 9: Improve pedestrian and bicycle connectivity.

4. Changes in Policies or Regulations
    - Recommendation 10: Increase carry-on limit for transit.
    - Recommendation 11: Allow vehicles to be used flexibly for passenger and food transportation.

Not all recommendations are necessarily appropriate or applicable to every community. Many of the recommendations are most appropriate for improving food access for people that do not have access to a car and for people with limited income. These are environmental justice populations that are vulnerable to food insecurity, and for whom changes to improve food access will have the greatest impact.

The findings of this study show that food access varies greatly across Massachusetts, and available transportation mode. Since food access is significantly lower (and less equitable) for people without access to a car, efforts should be made to make food more accessible by non-automobile modes like walking, bicycling, and transit.

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List of Acronyms

Acronym	Expansion
ANOVA	Analysis of Variance
ARP	American Rescue Plan
CARES	Coronavirus Aid, Relief, and Economic Security
CHAID	Chi-square Automatic Interaction Detector
CRRSAA	Coronavirus Response and Relief Supplemental Appropriations Act
CV	Coefficient of Variation
FoodAPS	Food Acquisition and Purchase Survey
FRTA	Franklin Regional Transit Authority
FTA	Federal Transit Administration
GBM	Gradient Boosted Model
GIS	Geographic Information System
HFAI	Healthy Food Availability Index
MAE	Mean Absolute Error
MArtap	Massachusetts Rural Transit Assistance Program
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
MPO	Metropolitan Planning Organization
NEMS	Nutrition Environment Measure Survey
OOB	Out-Of-Bag
PVTA	Pioneer Valley Transit Authority
REJ+	Regional Environmental Justice Plus
RMSE	Root Mean Square Error (RMSE)
SNAP	Supplemental Nutrition Assistance Program
SPI	Standardized Price Index
SPR	State Planning and Research
USDA	United States Department of Agriculture

1 Introduction

This study of Measuring Food Access to Improve Health was undertaken as part of the Massachusetts Department of Transportation Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

Transportation is an important determinant of public health. Inequitable access to jobs, health care services, and food have been shown to be significant contributors to health disparities. Data from a variety of sources can be used to identify gaps in accessibility, but there remains a need to systematically identify these gaps and the actions that can be taken by public officials to address them.

1.1 Project Overview

Inequitable access to jobs, health care services, and food have been shown to be significant contributors to health disparities. Data from a variety of sources can be used to identify gaps in accessibility, but there remains a need to systematically identify these gaps and the actions that can be taken by public officials to address them.

The Massachusetts Department of Transportation (MassDOT) has been a pioneer in recognizing the connection between transportation and public health. Efforts in that direction include health-related design guidelines as expressed through the *2009 Healthy Transportation Compact* and the *2013 Healthy Transportation Policy Directive*. A more recent MassDOT project titled: "Public Health Assessment for Transportation Projects" summarized health impact modeling tools, decision-making processes, and project scoring and prioritization frameworks across the nation. The focus was on project scoring criteria and metrics used to assess health impacts of transportation, accounting for multiple pathways such as accessibility, safety, air quality, equity, and physical activity. This project found that while accessibility is lacking from health impact models, it is the second most common health-related factor, after safety, included in project scoring and prioritization frameworks.

The degree to which people physically have access to various kinds of destinations significantly affects well-being; for example, access to not only jobs and education but, access to health care, food, and recreational activities each directly affect health outcomes. The goal of this project is to document metrics and methodologies used to assess accessibility and correlate them with other socioeconomic and demographic characteristics in an effort to assess inequities associated with the lack of accessibility that often leads to health disparities. An effort will also be made to document policies and practices that can be used to address such gaps. The main outcome of this research will be a methodology for identifying accessibility gaps and a set of recommendations for various stakeholders (e.g., transportation and health agencies) that can be used to address accessibility-induced transportation inequities. These products should support MassDOT's existing accessibility initiatives and data dashboards to continuously monitor accessibility gaps and inequities that affect public health.

1.2 Study Objectives

The objectives of this research are twofold:

1. Link metrics of access to social determinants of health, such as access to health care, open space for physical activity, educational opportunities, housing, and food, with demographic and socioeconomic data to identify the most critical accessibility gaps.

2. Recommended targeted actions that can be made by public officials to address inequities will be recommended.

There are two products of this research: (1) the documentation of gaps in access to food, evaluated across time, demographic groups, and locations across Massachusetts, and (2) a guidebook that includes recommendations for how stakeholders can address the specific types of identified accessibility gaps to reduce inequities. The methods are based on using existing statewide data sources so that analyses are consistent and comparable across the state. These products will support MassDOT's existing accessibility initiatives and data dashboards to continuously monitor accessibility gaps and inequities that affect public health.

2 Literature Review

2.1 Accessibility and Public Health

Accessibility is defined as the ease of reaching facilities and activities. One of the more complete definitions also includes “a person’s ability to reach necessary or desired activities using the available transportation modes in an urban area.” (*1*). Accessibility can be targeted at different types of opportunities that might be of interest, food retailers, jobs, recreational activities, or healthcare.

Access to jobs is a social determinant of health as it directly influences a household’s income and therein access to multiple other goods and services including transportation options, healthcare, education, etc. Access to goods and services is another major determinant of health. Lack of proximity and transportation options to access hospitals/medical centers or healthcare providers has been documented to be obstacles to receiving sufficient healthcare services (*2,3*). Access to education not only improves one’s potential to gain access to well-paying employment opportunities, which are also strongly correlated with health outcomes, it has also been found to influence people’s behaviors toward a healthier lifestyle. Highly educated individuals are more likely to engage in physical activity and seek out preventive health measures (*4*). Access to recreational activities encourages physical activity as well as social interactions that benefit mental health. Access to transit motivates physical activity but also has some indirect health benefits through the reduction in air pollution and traffic accidents (*5*). In addition, it improves overall accessibility for disadvantaged populations bringing additional health benefits. Finally, access to high quality food has been found to be negatively correlated with chronic disease such as diabetes and cardiovascular diseases as well as obesity (*6*).

Food access is a principal topic to examine as it is strongly associated with an individual’s health outcomes. The food environment can promote or discourage a healthy diet depending on the variety of products available. Some communities are not in areas with access to nutritious food retailers. Even in cases where healthy food retail options are present, they are not necessarily accessible economically or in terms of transportation. Accessibility barriers associated with race, ethnicity, and vehicle ownership are some of the socioeconomic factors that have the largest impact on access to food. Food insecurity is an ever present problem in North America affecting 8% of Canadian households (*7*) and 15% of US households (*8*). Almost 53.6 million Americans live in a food desert based on the USDA’s definition (*9*). Nationally, almost 97% of food desert residents meet the criteria for the Supplemental Nutrition Assistance Program (SNAP) and almost 20% of Black families do not have stable access to food (*10*).

2.2 Definitions of Food Access

Access to food has been described through the lens of socioeconomic characteristics to reveal the relationship between available food stores and community access. *Food desert*, *food swamp*, *food hinterland*, *food security* and *food insecurity* are all terms used to describe a lack of accessible food options. In general, food access is defined as the ability to obtain food items needed from outlets that are available within a neighborhood (*11*) or as a person's ability to find and afford food (*12*).

A variety of studies present the definition of *food desert*. In the Food, Conservation, and Energy Act of 2008 (*13*) food desert is described as an area with limited access to supermarkets, supercenters, grocery stores, or other sources of healthy and affordable food that may make it harder for some Americans to eat a healthy diet. The US Department of Agriculture provides the following approach to describe food deserts:

"Limited access to supermarkets, supercenters, grocery stores, or other sources of healthy and affordable food may make it harder for some people to eat a healthy diet in this country. There are many ways to measure food store access for individuals and for neighborhoods, and many ways to define which areas are low-income and low access neighborhoods that lack healthy food sources. Most measures and definitions consider at least some of the following indicators of access:

1. Access to sources of healthy food, as measured by distance to a store or by the number of stores in an area;

2. Individual-level resources that may affect accessibility, such as family income or vehicle availability; and

3. Neighborhood-level indicators of resources, such as the average income of the neighborhood and the availability of public transportation." (*14*)

Conversely, a *food swamp* is a place where unhealthy foods are more present than healthy foods. Food swamps typically exist in food deserts where there are limited options of healthy foods and instead feature an overabundance of unhealthy alternatives. A food swamp might be an area where there are plenty of small corner stores, but no healthy food options, such as supermarkets or farmers' markets (*15*).

The term of *food hinterlands* is introduced in (*16*) as areas with poor food access that are away from the food deserts that are within a city or urban area. These are often areas with lower population density, usually dispersed suburban areas.

Food security is a situation in which all community residents obtain a safe, culturally acceptable, nutritionally adequate diet through a sustainable food system that maximizes community self-reliance and social justice (*17*). It is noted that food security has been modified many times since 1970s (*18*). Both food security and insecurity are expressed in levels by the USDA as:

Food Security

1. High food security: no reported indications of food access problems or limitations.

2. Marginal food security: one or two reported indications—typically of anxiety over food sufficiency or shortage of food in the house. Little or no indication of changes in diets or food intake.

Food Insecurity

1. Low food security: reports of reduced quality, variety, or desirability of diet. Little or no indication of reduced food intake.

2. Very low food security: reports of multiple indications of disrupted eating patterns and reduced food intake." (*19*)

These terms collectively offer a comprehensive summary of conditions which characterize a relative lack of accessible healthy food options. Whether the origin of these accessibility issues stems from the scarcity of full-service supermarkets or from the oversaturation of unhealthy food options, the outcomes for residents in these areas uniformly manifest as an inability to reach the nutritious foods, which predispose a community to the positive health outcomes of a healthy and varied diet.

2.3 Food Access Metrics

The most common metrics used, are related to travel time or distance between food retailers and a point of interest. Other types of metrics that have been used are the density of food retailers within a bounded area as well as the quality of the products based on their nutrition. More recently, the product affordability, which is captured by the food prices and the frequency of visits to food retailers, are metrics used in identifying gaps in food access. A summary of food access metrics, their advantages, and their disadvantages is provided in Table A.1 in Appendix A.

Travel time has also been used as an accessibility metric. Chavis and Jones (*20*) defined travel time as the one-way travel time between the residence and the primary store. Another definition expresses travel time in relation to centroids of geographic areas and food stores (*21*) such as a census block (*22*) or census tract (*23*) centroid and the nearest store. The maximum time to get to a grocery store by walk, drive, bike and transit is another element, which should be considered as well (*24*).

In other studies, distance-based metrics were used in reference to either network distance or as a radial distance from a point of interest. Some studies described it as the mean distance from residential units to food stores (*11,25*). Another metric is the distance from a census block centroid to the nearest supermarket (*16,26*) or from the population-weighted centroid to the nearest store (*27*). In Leete et al. (*16*) the average distance to the three closest supermarkets is calculated. A combination of driving and straight-line distance between residence and primary store is another approach to measuring distance (*20*).

Food retailer density can also be used as an accessibility metric to determine gaps. For example, some studies have used a network distance of within one-quarter of a mile from the population-weighted center point (*28*) to capture the stores that are accessible within one-quarter and a half mile by walking as well as one and five miles by driving (*29*). Another way is to measure the number of supermarkets within one mile or kilometer from the census block centroid (*16,26*).

Regarding food quality assessment, one way is to use the healthy food availability index (HFAI) (*20,30*), which scores locations under study as higher when the variety, availability and quality of healthy foods is greater. Other studies consider whether or not stores accept SNAP vouchers (*20*) as a way to evaluate access to healthy food options.

Furthermore, food prices can be used to describe the economic accessibility of a given grocery store. Food staple prices, junk food prices, fruit and vegetable prices, and standardized price index (SPI) have been used to measure the affordability of the products (*31*). Another study uses three supermarkets so that they have variety in the prices and products, given that different supermarket companies provide many brands for the same product, with variability in discount prices (*26*).

The frequency of grocery stores visits in a week or in a month as well as the number of stores visited per month have also been used as accessibility metrics (*20,24*).

There are some studies that define unique metrics to measure food access. A recent study suggested using the travel cost from the census block group centroid to the nearest supermarket, that included the value of time and the operating cost as the food access metric (*32*). A retail potential index is structured to show if the inner or non-inner tracts are underserved, using the supplies of both areas (*33*). Finally, mapping higher or lower combinations of grocery stores and fast-food restaurants in clusters has been explored (*34*).

2.4 Data Needs for Food Access Metrics

Depending on the metric that is used, different data needs emerge.

- Travel times are usually provided by respondents using survey questions (*20,24*) but in the case of walking/transit travel times; pedestrian network, transit routes and schedules, as well as transit stops data is needed (*22*).

- The locations of food stores are necessary when calculating time and distance of trips (*11,16,21,23,25–27*) or calculating the density of food stores (*28,29*).

- Nutrient information and the United States Department of Agriculture (USDA) National Household Food Acquisition and Purchase Survey (FoodAPS) data are essential for identifying the quality of food products (*20,30*).

- Prices of products in various types of food stores are also necessary to allow for exploring food affordability (*26,31*).

- Frequency requires survey results as it is defined using the responses on how many times an individual visits a store (*20,24*).

To investigate the population groups that experience food access inequities, socioeconomic and demographic characteristic data is needed. Race, ethnicity, income and poverty level, educational attainment, vehicle ownership, age, gender, marital status, and household composition, public assistance (such as SNAP), and employment, are data which can be useful. Furthermore, data on the location of various of food retailers is essential for differentiating between healthy and unhealthy food options. Supermarkets, convenience stores, farmers' markets, fast-food restaurants are the main categories that have been used in the literature.

2.5 Tools to Assess Food Access

As noted in the literature review, there are a number of metrics and measures used to evaluate access to food retailers. These measures and metrics are developed through a variety of methodologies. The main approach for exploring access to food and identifying gaps is through spatial analysis, particularly using Geographic information system (GIS). The main GIS tool typically used for spatial analysis in food access is buffer analysis which creates a radius around a point of interest. This allows the number of food retailers within a given radius to be calculated. Network analyses are also used which can be used to display the number of stores within a driving distance based on real world network infrastructure.

Some analyses have been conducted using Euclidean (i.e., straight-line) distance (*16*). Many studies make use of the Network Analyst tool in ArcGIS, which is used to calculate either time or distance using the existing road network and its speed limit (*11,20,21,23,25,29*). Conveyal is a web-based analysis tool that allows for spatial analysis based on network travel times by existing modes, including fixed route public transit. The tool is already used by MassDOT to support long-range planning and create custom competitiveness measures for transit network redesigns (*35*). Spatial clustering of supermarkets and fast-food restaurants using SaTScan software, uses a spatial scan statistic, is another approach commonly used in food access research (*34*).

An important source of data and analytics related to food access in Massachusetts is the Massachusetts Food System Database, produced by the Metropolitan Area Planning Council (*36*). This database includes data on multiple types of food retailers, farmers' markets, stores accepting SNAP, retailers participating in the Healthy Incentives Program (HIP). The database also includes the Food Access Index, which was developed for MAPC as a composite measure of access with weights from 1 to 5 assigned to different types of food retailers (*29*):

1. Convenience stores <2,500 ft^2;

2. Convenience stores >2,500 ft^2, pharmacies, and drug stores;

3. Specialty food stores, meat markets, and fish and seafood markets;

4. Supermarkets and other grocery (except convenience stores) <10,000 ft^2, farmers' markets, and fruit and vegetable markets; and

5. Supermarkets and other grocery (except convenience) >10,000 ft^2.

Together, the data sets that compose the Food System Database provide important inputs for spatial analysis of food access in Massachusetts, which can be viewed through an interactive web portal or downloaded for use with other GIS software.

In addition to the spatial analysis, regression models have been estimated to capture differences in food access as a function of community income and housing density for stores of various types and sizes (*30*). Examples of these models have used food demand, food supply, level of highway accessibility as variables (*33*), as well as variables that affect shopping to the nearest store such as travel cost, number of stores visited in a month, fresh meat options of the store (*24*). Studies have also explored the relationship among obesity, distance to store, and standardized price index (*31*). All of these studies apply their analysis including socioeconomic characteristics for different population groups; e.g., low income versus high income. Another tool used in recent research is ArcGIS's cost distance tool which can calculate travel cost (*32*).

Finally, there are studies that use unique tools/methods to explore gaps in food access. For instance, differences in grocery store shopping behavior by car ownership have been assessed using descriptive statistics and analysis of variance (ANOVA) analyses using shopping from nearest grocery stores, number of grocery stores visited and the shopping frequency, comparing for each variable those with and without a car as variables (*24*). In order to examine relationships between variables, correlation matrices have been created (*20*). Moreover, Chi-Square Automatic Interaction Detector (CHAID) decision tree is another approach that builds a predictive model to determine which factors, such as income, education, number of stores within a distance, and the presence of stores within a given distance, are the best predictors of the outcome of a given dependent variable (*20*). Additionally, the KD2SFCA method measures spatial accessibility to food stores by integrating a kernel function in each step of the methodology and calculates spatial accessibility as the sum of available stores, defined by the food store weight over the population of a location (*21*). Finally, the Nutrition Environment Measure Survey (NEMS) tool has been used to measure the food environment based on quality, availability, and price scores (*37*).

2.6 Studies of Food Access

The findings of previous studies are related to demographic, socioeconomic and geographical characteristics. Race, ethnicity, income, car ownership, poverty level, and housing density are the most important components that determine access to quality food in different locations. The results reveal that the existence of other types of inequities (e.g., low versus high income communities) leads to inequities in food access as well.

People who live under the federal poverty line, which is $30,000 per household consisting of four people based federal guidelines (*38*), usually have limited access to high quality food sources. More specifically, in Vermont, one-third of the fifteen census tracts containing 10.2% of individuals below the poverty level was identified as a food desert (*25*). In Cincinnati, Ohio, transit-based accessibility was slightly higher for people living below the poverty level (*22*). Neighborhoods in Mississippi and Portland, Oregon, that are socioeconomically disadvantaged have worse overall accessibility to food retailers (*16,21*).

Race affects access to food in a similar way to the poverty level. For example, in Saint Louis, Missouri, those who live in mixed or white high poverty areas or in areas that have a higher percentage of African American individuals have lower access to food than those who live in white and higher-income communities (*34*). In Cincinnati, Ohio, Black or African American and older adults have worse access to supermarkets than those identified as white (*22*). In New York City, the lowest food desert scores existed on the Upper East Side, which is an area with mostly white, middle and upper-income residents, while block groups with a predominantly Black population had fewer healthy bodegas and supermarkets and a lower food desert index score (*28*).

Income and vehicle ownership also have an impact on food access. Access improves when smaller stores are included in the analysis, while national food chains or small stores are often not found in neighborhoods that are low income and have low car ownership (*11*). In Pittsburgh, Pennsylvania, low-income participants were found to be willing to travel further to reach stores with lower prices. These low prices were not indicative of food quality however, as obesity rates of those who buy from low price stores were higher (*31*). In Baltimore, Maryland, it was found that the frequency of visits to grocery stores per month increased with car ownership but did not change with income, while people with access to vehicles visited a larger number of stores in each month. Regardless of mode, people were willing to travel more than twenty minutes to reach a store (*24*). In the same city, it is found that the 44.5% of those who do not own a car chose transit to access supermarkets, while one in four residents, stated that public transportation was their primary means of visiting grocery stores (*20*).

Four study areas in the state of Indiana revealed that the cost to access healthy food providers was lower for urban areas than for rural ones when considering driving or walking modes (*32*). Moreover, in Massachusetts, it is found that populations in rural areas are highly dependent on cars in order to access food while low-income residents and SNAP recipients exhibit the lowest food access. However, the average vehicle access decreases as food access increases across Food Access Index scores at the block group level. Within this matrix, a score of 0 means lack of access to any food retailer and a score of 15 indicates access to at least the equivalent of one store of each category including grocery stores, farmers' markets, meat and fish markets, pharmacies, convenience stores (*29*). In Hamilton County, Ohio, in places where the travel time to supermarkets is less than 30 minutes, the low-income populations experience the lowest access to supermarkets (*39*). Census block groups in Colonia, Texas, with lower vehicle ownership rates had slightly higher access to supermarkets, grocery stores and fast-food restaurants (*27*).

Differences in housing density can also influence variations in food access. In central Massachusetts, the lack of food retailers in a community was associated with lower housing density and higher median household income (*30*). Another study of the Boston Metropolitan Area shows that 82.4% of inner-city census tracts are underserved by food retailers while the respective percentage in non-inner-city tracts is 55.4% (*33*). Beyond Massachusetts, a study in Somerset County, Maine, found that two of the eight grocery stores are in areas which have high population density while areas with low density feature three of the eight supermarkets (*37*). In Montreal Island, Quebec, Canada, supermarkets are primarily found in suburban areas while urban areas have greater diversity and variety of food retailer options (*26*).

A study that utilizes a variety of accessibility metrics and includes the four dimensions of household income, affordability of products, distance to food retailers and food quality would be the most complete, however no single study includes all four dimensions together. Diversity of food retailers is important as it guarantees variability both in prices and quality. Furthermore, including multiple sociodemographic indicators can provide more generalizable results by including a greater range of population groups.

A recent study in Massachusetts examined the accessibility of stores within ¼ and ½ miles by walking as well as 1 and 5 miles by driving (*29*). Both metrics were estimated using the GIS Network Analyst tool. This study categorizes food retailers as healthy and unhealthy using the area of the store as expressed by its floor area square footage. This is based on the assumption that larger stores are more likely to be providing a variety of products that include healthy food options. The percentage of single-parent households, those that are Black or African American, as well as Hispanic or Latino heads of household, and children under five years old are considered as key demographic variables. Additionally, the median household income, the rate of vehicle ownership, and the percent of households receiving SNAP benefits are included as significant determinates of food access. This study examines different community types as well (e.g., rural versus urban).

Another recent study in Baltimore, Maryland, uses both travel time and road network distance to stores to measure food access, while accounting for food quality and variety using household data such as employment and primary food store, as well as nutritional information (*40*). Various travel modes were also in this study considered including car, walk, and bus. This study structures correlation matrices to assess the relationship between transportation and demographic variables, finding that the travel time is the most important predictor of food access. Similarly, another study in Baltimore, Maryland, uses a variety of metrics related to frequency of visits, quality of products and distance between home and stores, to evaluate access to grocery stores (*20*). Another new study in Indiana, estimates three spatial autoregressive models in order to investigate correlations between travel costs and variables that include a variety of socioeconomic characteristics such as education, age, gender, household size, race/ethnicity (*32*).

Based on these studies, food access varies greatly across demographic groups, community types, and geographic locations. In certain parts of the country, such as Massachusetts, food retailers are scarce in rural and suburban areas, however, relative accessibility remains high due to the greater prevalence of automobile ownership. Other regions of the United States, such as the states of Indiana and Ohio, feature greater levels of food access in urban areas due to a greater availability of public transit alternatives to personal vehicle use. Similar variability can be found when comparing communities based on their demographic characteristics.

Generally speaking, low-income households, households receiving SNAP benefits, and areas with high proportions of racial minority populations had the lowest access to full-service grocery stores. These groups were also found to be more willing to travel greater distances to access affordable food options, although the affordability alone was not necessarily indicative of better health outcomes. Vehicle ownership emerged as an additional key predictor of food access across community types and demographic groups. Households that had access to a car had access to the largest number of grocery stores, visited a greater diversity of grocery stores, and made more frequent trips per month to their respective food retailers. All of these benefits indicate an overall predisposition to automobile dependence for accessing healthier food options.

A key finding is the necessity of measuring food access using a multidimensional approach. Rather than viewing food access as binary, and only influenced by travel time, more comprehensive studies account for a variety of contributing factors such as household income, affordability of products, distance to food retailers and quality of products available. These compound metrics allow for a greater diversity of food retailers and households to be represented when assessing food access.

2.7 Limitations of Existing Studies

Given that income, distance, affordability, and quality have been identified as important predictors of food access, studies are limited when any of those is excluded. More specifically, there are studies that consider only distance (*11,25,27,28*) and others only travel time (*21–23*), with only one taking into account the variability of travel time during the day (*22*). Another study considers only prices and the marketing of the store such as the view of the store's main entrance and the store displays inside the store (*31*). Distance or travel time are not included in (*30*) where the focus is on the quality of products that are available at different stores.

Additional limitations of these studies concern those related to how the accessibility metrics are calculated and concerns about what data is being used. For instance, Euclidean distance does not account for congestion that could be affecting travel times (*16*). Furthermore, some studies assume that residents buy food from the nearest food retailer (*25*) or the major food retailer (*31*) rather than a variety of possible stores in their area. Additionally, mere focus on rural areas (*25*) or poor neighborhoods (*28*) excludes the socioeconomically vulnerable population living in urban and high-income areas, assuming that they have access to food stores. Public transit and its impact on accessibility is not always considered (*16,29,41*). In some instances, e.g., (*41*) only people with access to a vehicle are studied, excluding people do not have access to a car.

In this study, we include a variety of sociodemographic characteristics such as race, ethnicity, population density, vehicle ownership rate, poverty level and percentage minority population and identify which population groups lack of access to food retailers, including grocery stores, farmers' markets, and convenience stores so that different combinations product nutrition and affordability. An important distinction from the literature is that we use the square footage of accessible stores as a measure for food access rather than a simple count of retailers that can be reached, because square footage serves as a proxy for the range of foods that are available to choose from.

3 Research Methodology

The research approach for this study consists of five main components. First, data sources on food retailers and the socioeconomic characteristics of communities are presented. Second, a spatial analysis is conducted to quantify the number and square footage of supermarkets that can be reached within a defined distance or travel time from a census tract centroid. Third, an equity analysis is conducted to compare the distribution of food access across Massachusetts. Fourth, the socioeconomic data and food access data are linked with a machine learning method to model the food access for each census tract. The residuals of this model indicate the food access in a community relative to statewide trends. Finally, focus groups were held to discuss the quantitative findings and qualitative issues related to food access in two communities within Massachusetts. These sections culminate in a set of recommendations for policies and investments that can be made to meaningfully improve food access.

3.1 Data Sources

The analysis of food access requires linking data about the locations where food can be purchased and socioeconomic and demographic characteristics of census tracts that serve as this study's unit of analysis. A comprehensive database of food retailers provided by the Metropolitan Area Planning Council, which includes the following data fields for each store based on data in 2016:

- Store Type (convenience store, supermarket, pharmacy and drug store, meat market, fish and seafood market, fruit and vegetable market)
- Street Address
- Latitude/Longitude
- Store Size (square footage)

Additional data on the locations of farmers' markets and convenience stores is available from the Commonwealth of Massachusetts (2021). This analysis focuses on stores in the supermarket category, which are most likely to sell the full range of foods that a household may need. Of the 3,592 supermarkets in the database, 1,774 entries were designated as unverified and appeared to be closed businesses. An additional seventeen stores appeared to be duplicate records based on the address information. The cleaned data set contains 1,801 supermarkets across the state of Massachusetts.

The following demographic and socioeconomic data was also collected from the census to characterize each of the 1,472 census tracts in Massachusetts using 2016 data to match the year of data on food retailers:

- Population Density: The number of residents per square mile within a census tract.

- Vehicle Ownership per Capita: The number of vehicles registered to owners in a census tract divided by the total population of the census tract.

- Percent of Population in Poverty: The number of residents living below the Federal Poverty Line as defined by the US Department of Health and Human Services (e.g., household income under $30,000 for a family of four) divided by the total population of the census tract.

- Percent of Population Identifying as Racial or Ethnic Minority: The number of residents that identify as Latino/Hispanic, Black/African, American Indian and Alaska Native, Asian, Native Hawaiian, and Other Pacific Islanders, divided by the total population of the census tract.

Figure 3.1 shows the distribution of population density (people per square mile) across Massachusetts. The population is highly concentrated in the eastern part of the state near the coast. Most of the other urban areas outside of Boston are designated by the Massachusetts state legislature as “Gateway Cities,” which are midsize cities that have faced social and economic challenges in the wake of industrial decline. The distribution of population reveals a range of communities in urban, suburban, and rural environments.

A socioeconomic measure that is relevant to food access is the level of vehicle ownership, represented as the number of vehicles per person. Figure 3.2 shows that car ownership (represented as vehicles per person) is lower in cities such as Boston and Springfield than in suburban and rural areas. This can be explained by the fact that large cities characterized by high population densities feature multiple means of transportation, allowing residents to make use of many alternative modes of transportation. However, in suburban and rural areas where driving a personal vehicle is only feasible choice, vehicle ownership is high as noted for the west side of the state.

Two other socioeconomic measures that are related to environmental justice are the percent of population in each census tract that identify as a racial or ethnic minority (Figure 3.3) or are living in poverty (Figure 3.4). The percent of minority populations is defined as the percent of the population that is Latino/Hispanic, Black/African, American Indian and Alaska Native, Asian, Native Hawaiian and Other Pacific Islander within each census tract. The highest concentrations of minority population are in urban areas such as Boston, Lowell, Worcester, and Springfield. Although the poverty rate is higher in some urban centers, there are also rural communities in the western and southeastern parts of the state with elevated poverty rates.

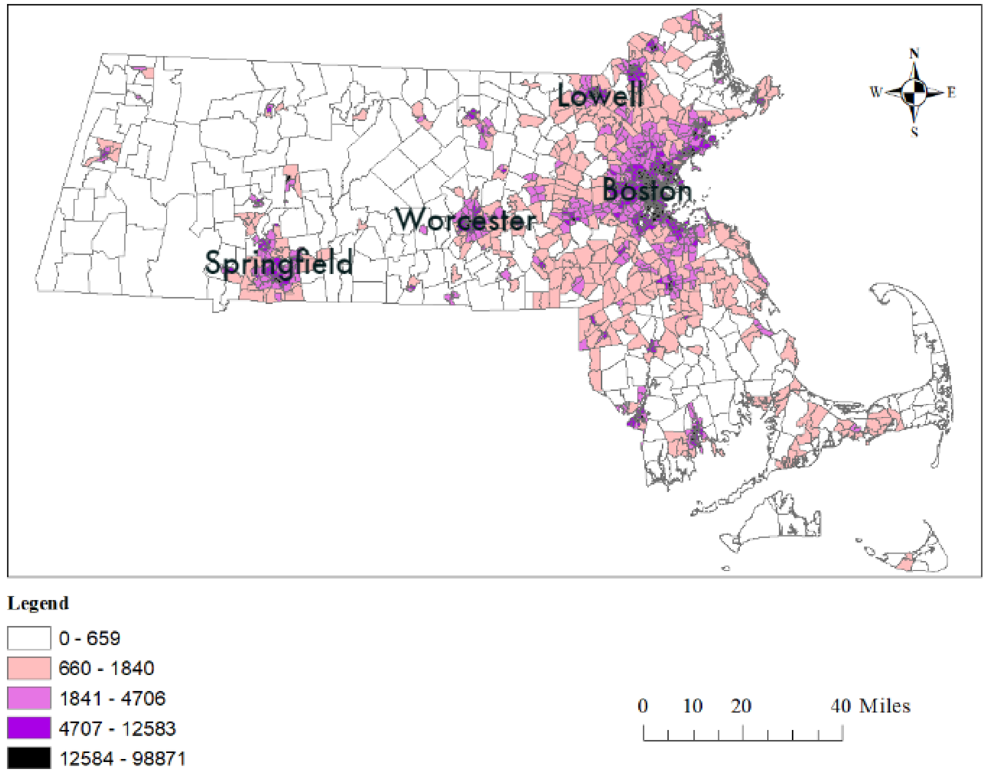


Figure 3.1 Population density

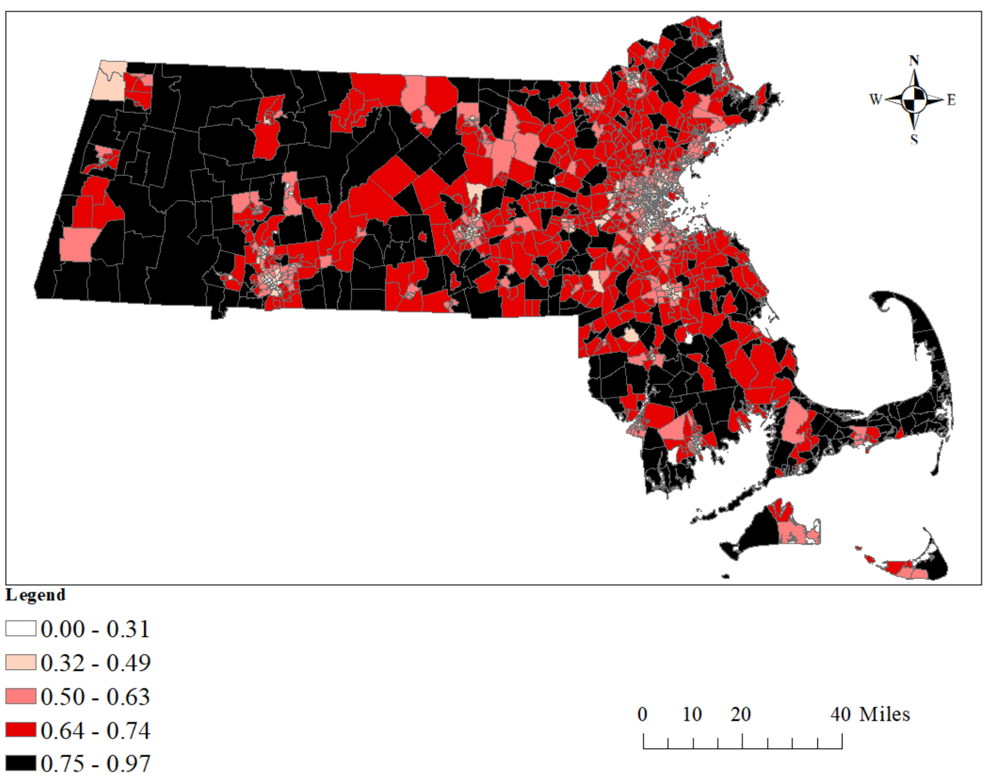


Figure 3.2 Vehicle ownership

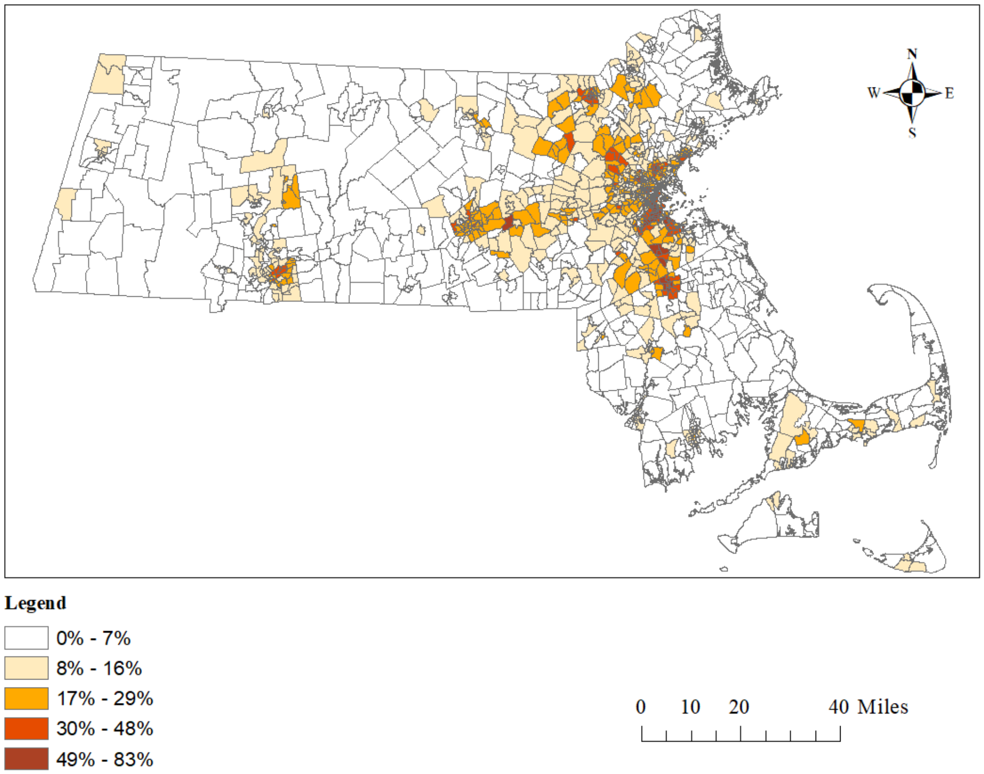


Figure 3.3 Ethnic or racial minority (%)

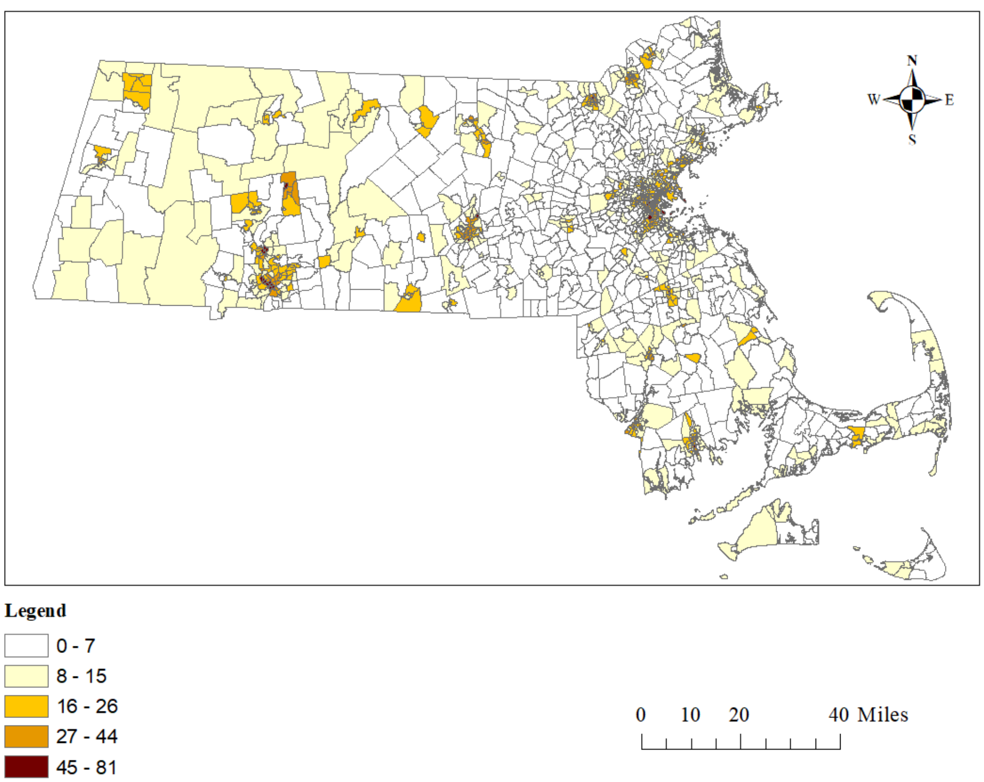


Figure 3.4 Population in poverty (%)

3.2 Spatial Analysis

To investigate food access, ArcGIS 10.8.2 was used to analyze data at the geographic scale of census tracts. The analysis was simplified by associating the socioeconomic characteristics of each census tract with the tract's centroid and calculating food access from that point. This study explored four transportation modes to access food retailers: walking, biking, driving, and walk/transit.

3.2.1 Distance-Based Spatial Analysis

In this study, we first compared food access based on the number of stores within a buffer distance of each census tract centroid. This is a straight-line distance measure that appears as a circular area when mapped around each centroid. Based on the literature, two distance thresholds are considered: ¼ mile for walkability (*42,43*), and 1 mile for driving (*29*). Comparisons are made for three types of food retailers, which are assumed to provide different types and price ranges of food:

1 Supermarkets: Stores that are most likely to sell a variety of foods, including healthy products, although affordability can vary significantly from one store to another.

2 Farmers' markets: Opportunities to purchase healthy food options directly from farmers or producers. Prices vary and are sometimes high, and markets may may have limited selection or only be open for a few hours per week or certain times of the year.

3 Convenience Stores: Smaller stores that are more likely to stock processed and unhealthy foods.

As mentioned in Section 2, straight-line distance-based access metrics do not accurately capture the distance since they are not based on the actual transportation network. In addition, distance-based access metrics do not account for traffic conditions or differences between modes used. As a result, the rest of the analyses (i.e., additional spatial analysis, equity analysis, machine learning, and the basis for the focus groups) presented in this study has been performed with a travel time-based accessibility metric as described next. The analyses also focus on only one type of food retailer, the supermarkets, in recognition that they offer the greatest variety of foods at wide price ranges.

3.2.2 Travel Time–Based Spatial Analysis

An alternative to measuring food access with a fixed distance constraint is to consider how far a person can travel on the actual transportation network within a travel time budget (i.e., constraint). For this, we made use of Conveyal (https://conveyal.com/), a spatial analysis tool to evaluate travel time thresholds instead, because these account for both the travel distances on the network as well as speeds. A travel time constraint of 10 minutes is used for walking, biking, and driving. A travel time constraint for 30 minutes is used for walk/transit trips to allow for waiting time associated with transit headways. Conveyal was used to determine which supermarkets are accessible within the travel time thresholds for each mode and census tract centroid. For modes, such as public transit, in which travel times vary depending on when a trip starts relative to a published transit schedule, the 50th percentile travel time from Conveyal was used.

One problem with defining food access as the number of stores within the accessible distance or travel time is that not all stores offer the same variety of food choices. The data set reports store size in four discrete categories, as defined in Table 3.1. Since one large supermarket is likely to offer a greater range of healthy food options than a small corner market, square footage of supermarket space may serve as a more suitable measure of food access. Floor area is a proxy for the diversity of foods available for purchase, so we propose using total accessible square footage of supermarkets as a measure of food access. This value is calculated by summing the estimates of the median square footage for each of the accessible supermarkets within the travel time threshold. The estimated size for supermarkets in the >40,000 square foot category is 70,000 ft^2, which is the size of a typical, large, full-service supermarket.

Table 3.1 Estimated supermarket size for each category

Supermarket size category (ft^2)	Estimated median supermarket size (ft^2)
< 2,499	1,250
2,500–9,999	6,250
10,000–39,999	25,000
> 40,000	70,000

3.3 Equity Analysis

One method used to analyze the equitability of food access across Massachusetts is the use of Lorenz. A Lorenz curve is typically used to graphically represent the distribution of wealth in a population by ordering individuals from least to greatest wealth and plotting the cumulative wealth against the total population (*44*). We adapted the Lorenz curve method to represent the distribution of food access rather than wealth. First, the population-weighted food access for each census tract was calculated by multiplying the accessible square footage of supermarkets by the census tract population. Then, the census tracts were sorted in ascending order of weighted food access. Finally, a Lorenz curve was constructed by plotting the cumulative share of total weighted food access (vertical axis) versus the cumulative share of population (horizontal axis).

3.4 Machine Learning

Machine learning methods were used to identify the relationship between the various socioeconomic factors and food access in each census tract. Two primary methods were considered. The gradient boosted model (GBM) is an ensemble method that uses multiple weaker models to make stronger predictions using decision trees with high flexibility (*45*).

The GBM method first trains a decision tree in which every observation has an equal weight. The predictions of the final ensemble model are weighted sums of the predictions made by the previous tree models. A useful outcome of the model fitting process is the GBM's ability to identify the most important explanatory factors that are correlated with the target variable.

Four models were developed to predict food access by each of the four modes of interest (i.e., 10 minutes walking, biking, driving, and 30 minutes walking/transit) based on the socioeconomic measures (i.e., population density, vehicles per person, percent minority, and percent in poverty). Socioeconomic and food access data were associated with the centroids of each of the 1,472 census tracts in Massachusetts.

Collinearity between the explanatory variables was evaluated using the correlation matrix, as shown for 10 minutes walking in Figure 3.5. Nonlinear relationships between food access (the target variable) and the other factors for all modes (see Figure 3.5 through Figure 3.8) indicate that nonlinear modeling methods are needed for this analysis. The GBM is a nonlinear/nonparametric method that can also address issues related to correlation through regularization. The GBMs developed in this study predict the relative food access for every census tract by each of the four modes.

In particular, the four GBMs developed in this study used 80% of the data to train the model and 20% of the data for testing. The number of boosting stages, indicated as the number of estimators in Figure 3.9, are chosen in a range $n \in [200, 1000]$, with a step of 200. The maximum depth, which limits the number of nodes in the tree, is chosen from the values $m \in \{1,3,5,7\}$ based on the best Out-Of-Bag error (OOB). Values lower than 1.0 for the subsample result in Stochastic Gradient Boosting. Typically, values around 0.8 work well. Figure 3.9 shows that $m = 7$ and $n = 200$ corresponds to the lowest OOB for the GBM for food access for all modes, so this combination was selected for the four models.

3.5 Focus Groups

In addition to the quantitative analysis using the methods described above, this study also includes focus group meetings with stakeholders in two specific communities. The purpose of the focus groups is to speak with representatives of organizations working at the intersection of transportation and food access to understand if the findings of the quantitative analysis are representative of the food access challenges on the ground. Additionally, these focus groups can provide insights about the specific challenges related to food insecurity in study communities, which can better inform the types of policy or transportation investments that might be most impactful for improving food access.

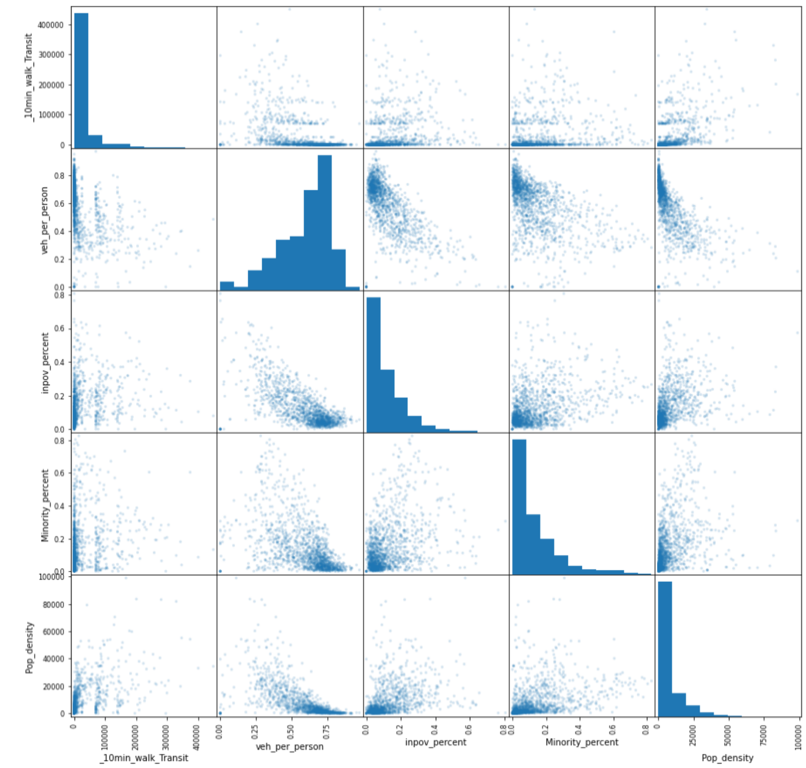


Figure 3.5 Correlation matrix for food access within 10 minutes walking

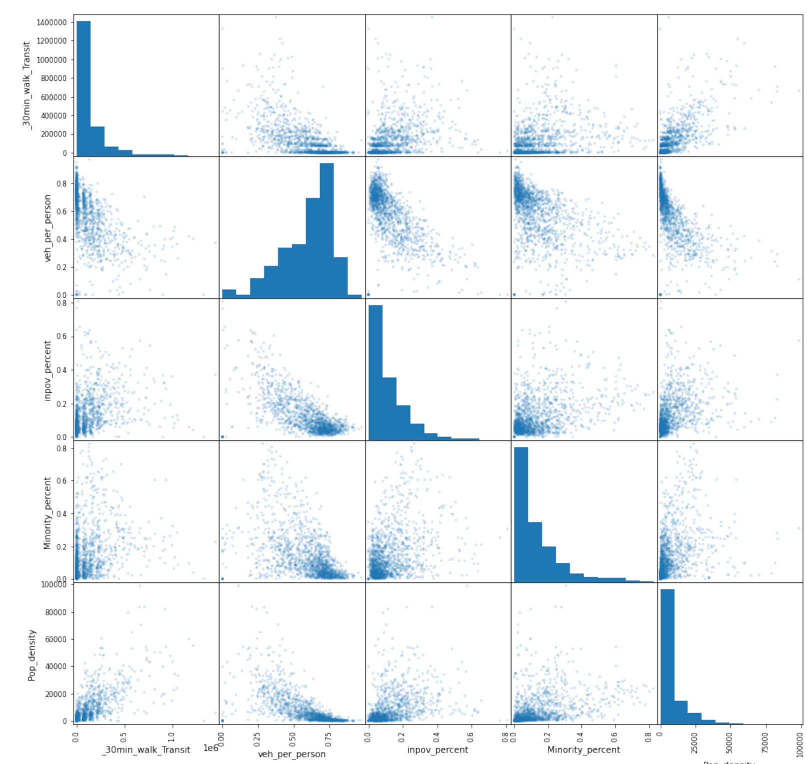


Figure 3.6 Correlation matrix for food access within 30 minutes by walk/transit

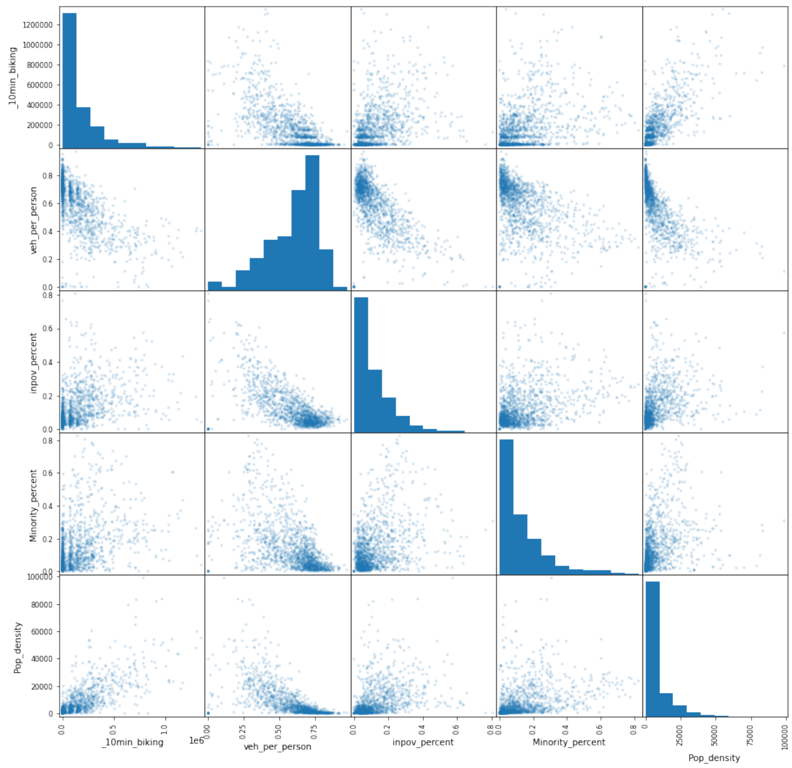


Figure 3.7 Correlation matrix for food access within 10 minutes biking

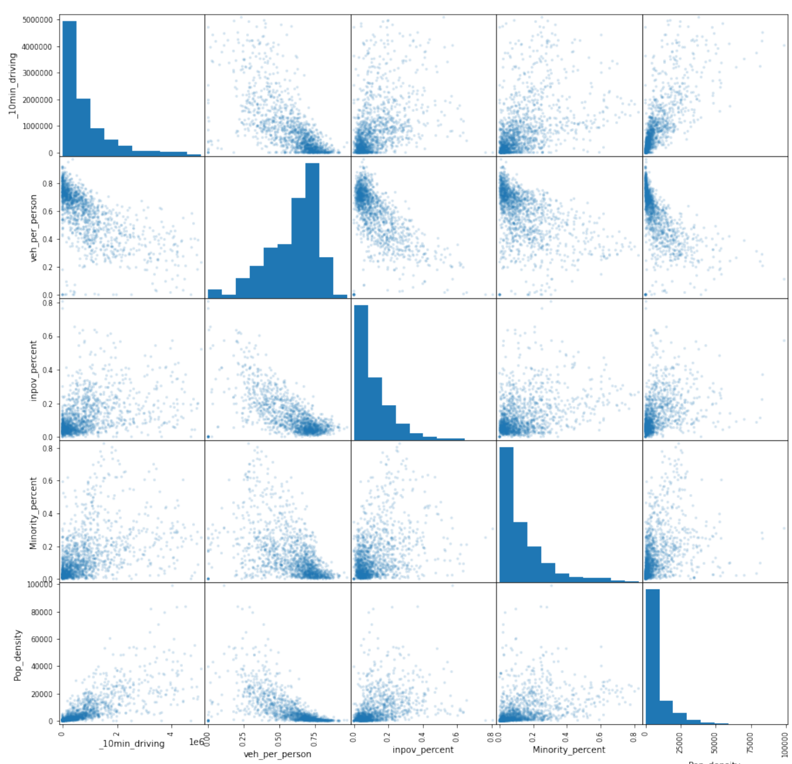
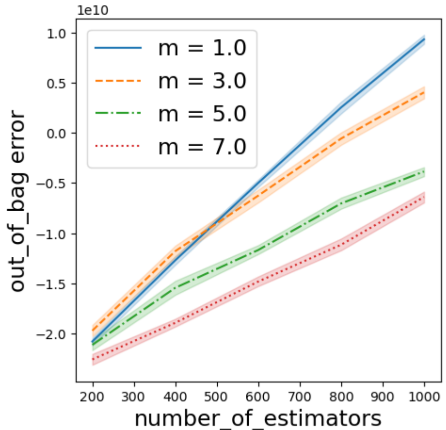
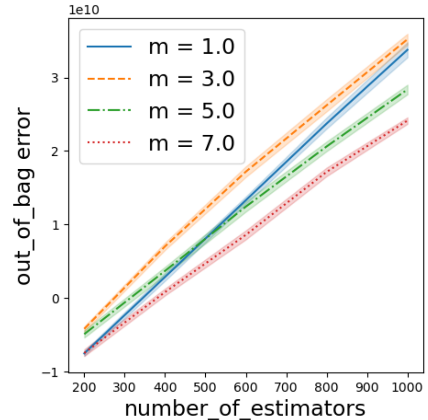


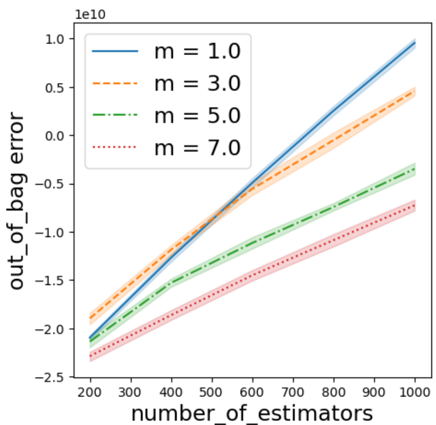
Figure 3.8 Correlation matrix for food access within 10 minutes driving



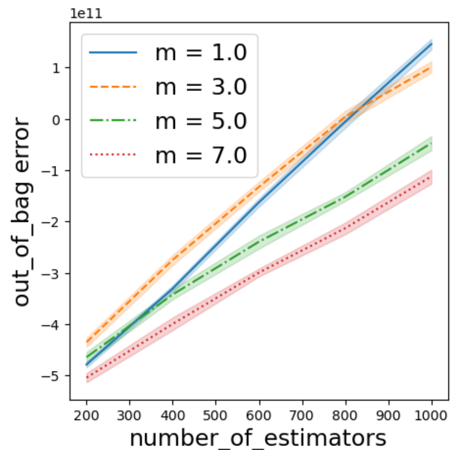
(a) 10 minutes walking



(b) 30 minutes walk/transit



(c) 10 minutes biking



(d) 10 minutes driving

Figure 3.9 GBM performance based on the number of estimators for all four modes

3.2.3 Focus Group Community Selection

The selection of the focus groups were conducted with input from MassDOT that utilized information from the recently compiled Regional Environmental Justice Plus (REJ+) data layer. The REJ+ layer was included in the selection of communities to ensure that focus groups were engaging with some of the most social economically vulnerable communities in the state. More specifically, the REJ+ shapefile layer highlights census block groups that meet traditional environmental justice criteria of

- **Income:** annual median household income ≤ Metropolitan Planning Organization's (MPO) [2]5th percentile,
- **Race and ethnicity:** percent of individuals that identify as Hispanic or Latino; Black or African American; American Indian or Alaska Native; Asian; Native Hawaiian or

Other Pacific Islander; Some other race; or Two or more races and do not identify as White alone ≥ MPO's 75th percentile; and

- **Limited English proficiency (LEP):** percent of households with limited English-speaking members ≥ MPO's 75th percentile.

This layer also makes the addition of the "Plus" designation, which adds further socioeconomic characteristics of

- **Car ownership:** percent of households without an available vehicle ≥ MPO's 75th percentile,

- **Disability:** percent of households with one or more persons with a disability ≥ MPO's 75th percentile, and

- **Age:** percent of individuals aged 65 or older ≥ MPO's 75th percentile.

These threshold values are calculated relative to MPO regions rather than statewide values in order to capture regional inequities which might be underrepresented at the state level. This data layer also includes a new designation of the "Most Dominant Factor," which highlights which of the socioeconomic indicators has the greatest dissimilarity from each respective regional threshold.

The REJ+ data set was then joined with the GIS file containing information on the square footage that is accessible from each census tract using the four different modes. This was followed by a filtering process to identify census tracts that were

- below median grocery store access by square footage via 30-min walk/transit,

- contained at least one REJ+ designated block group,

- included zero-vehicle households as the most dominant socioeconomic factor.

After filtering all census tracts, nine emerged as possible communities in which focus groups could be held. Focusing on those communities would allow us to better understand the local context and experience of residents in communities, which the data suggests has transportation barriers to food access and demographic predispositions to dependance on the transportation system. Three community types were identified based on relative population density to capture the experiences of residents in rural, suburban, and urban areas. One community from each category was then selected as follows:

- Urban community: Worcester,

- Suburban community: Amherst, and

- Rural community: Deerfield.

Following the selection of the communities, the research team, using input from MassDOT reached out to several food access related community stakeholder organizations within each of these communities, such as regional transit agencies, Mass in Motion coordinators, councils on aging/senior centers, and food pantry/food charity organizations.

3.2.4 Focus Group Structure

The focus groups were organized as online meetings on Zoom comprised of invited participants from relevant stakeholder organizations as well as moderators from the University of Massachusetts and MassDOT Office of Transportation Planning. These meetings were scheduled for 1.5 hours to allow sufficient time for briefing on the technical analysis, discussion of the prepared questions, and additional time for other related discussion. The structure of the meetings was as follows:

- **Introductions:** Research Team and Participants.
- **Brief Explanation of Study:** An approximate 5-minute presentation by the research team on measuring food access and looking for access gaps that have a spatial/transportation component; show what the data looks like for the state and the focus community. Slides used for this part of the focus group are included in Appendix B.
- **Structured Discussion:** the following questions were posed to the group, with time for each participant to respond and allow for some follow-up questions that may arise.
    1. Are there known locations in the community that present gaps in food access?
    2. Does the statewide analysis appear consistent with your understanding of food access in the community or is there something else important that this does not catch?
    3. What role does transportation play as a barrier to food access? How big is the discrepancy for people with and without access to a car?
    4. What programs exist or have been tried to improve food access? Are/were they successful?
    5. What would be the most impactful way to improve food access in the community? Are there transportation investments that would make a difference?
- **Conclusion:** Allowed each participant an opportunity to share any other information that seems relevant.

4 Results

The results are presented in four subsections. First, the results of the spatial analysis show the measured food access across Massachusetts, and how this varies by transportation mode using both distance and travel time thresholds as the accessibility metrics. Second, the equity analysis using Lorenz curves reveals the differences in the equitable distribution of food access by the different modes using travel time thresholds. Third, the machine learning results show which communities have relatively less food access compared to other similar communities in Massachusetts. Finally, the results of the focus groups are summarized.

4.1 Spatial Analysis

Using the spatial analysis method described in Section 3.2, food access is first compared by measuring the number of food retailers within ¼ mile and 1 mile distance thresholds of the census tract centroids. Comparisons for the number of supermarkets are shown in Figure 4.1 and Figure 4.2; for the number of farmers' markets in Figure 4.3 and Figure 4.4; and for the number of convenience stores in Figure 4.5 and Figure 4.6. The figures show that food retailers are more concentrated in urban areas, with many suburban and rural parts of Massachusetts not having a single store with the distance threshold of interest. Although supermarkets and convenience stores are abundant, there are relatively few farmers' markets. Despite their relative scarcity farmers' markets are more likely to be located in rural areas, due to their close proximity to suppliers.

As discussed in Section 3.2, we proposed using the square footage of reachable supermarkets as a more meaningful measure of food access and evaluating travel time thresholds by each of the four transportation modes (10 minutes walking, 30 minutes walk/transit, 10 minutes biking, and 10 minutes driving) rather the straight-line distances from census tract centroids. The results are shown in Figure 4.7 through Figure 4.10. These four figures use the same color scale, to illustrate that driving provides significantly greater food access in most communities than any of the other modes. Across all modes, the food tends to be the most accessible in urban areas with high population densities (e.g., Boston, Lowell, and Springfield), because the large customer base supports more and larger supermarkets. The urban areas with the highest population densities also tend to have higher minority populations, higher poverty rate, and lower vehicle ownership, as shown in Figure 3.1 through Figure 3.4.

On its own, this spatial analysis provides a quantitative measure of food access, which confirms that food is generally less accessible in suburban and rural communities than in the densest urban areas. By this measure, sparsely populated parts of the state appear to have gaps in food access, but rural areas are not expected to have the same density of food retailers as urban areas. A deeper analysis is needed to link the socioeconomic characteristics of census tracts and food access and to address equity concerns by identifying communities that are underserved relative to statewide trends.

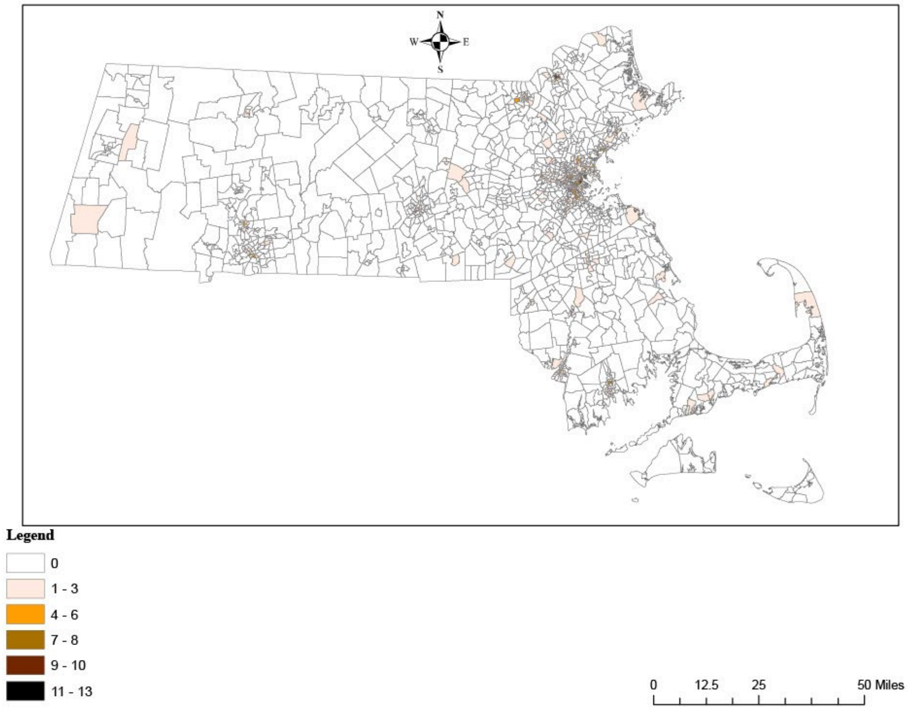


Figure 4.1 Supermarkets within one-quarter mile

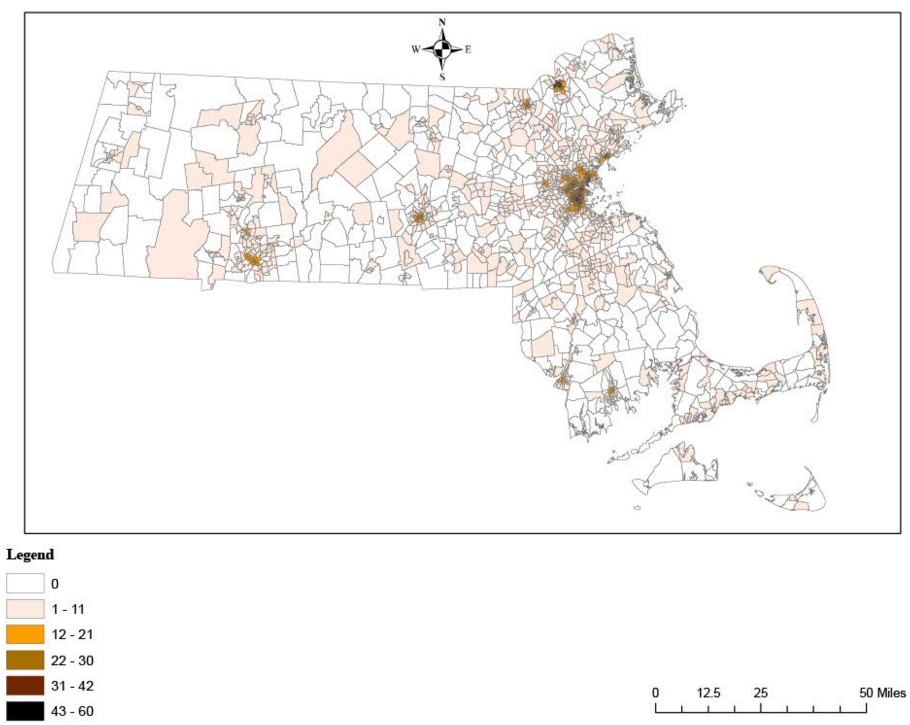


Figure 4.2 Supermarkets within 1 mile

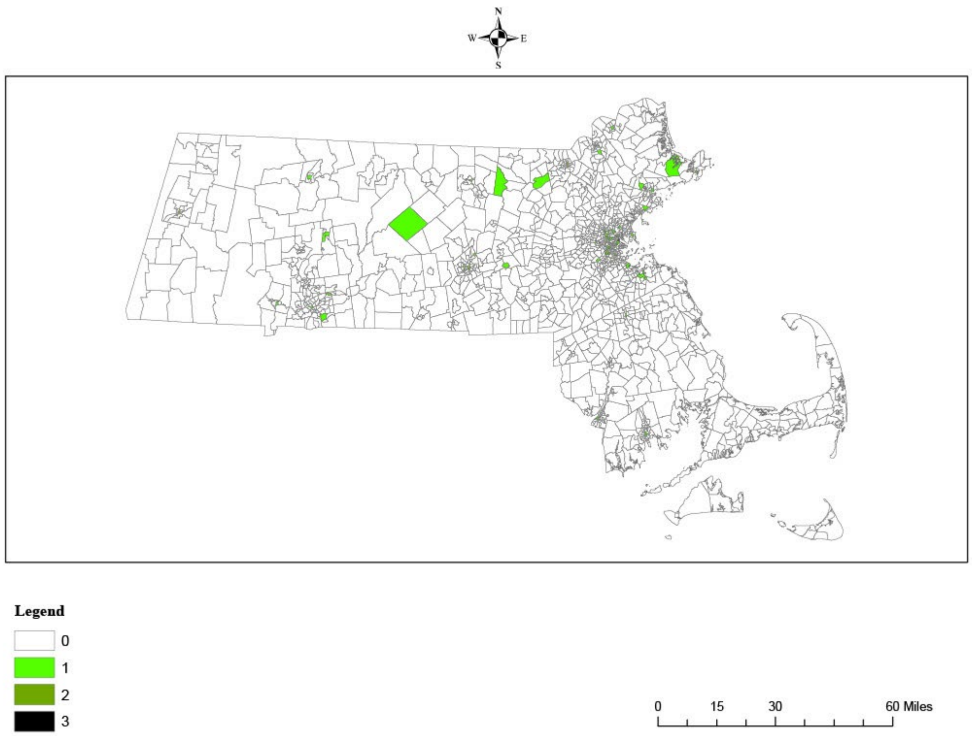


Figure 4.3 Farmers' markets within one-quarter mile

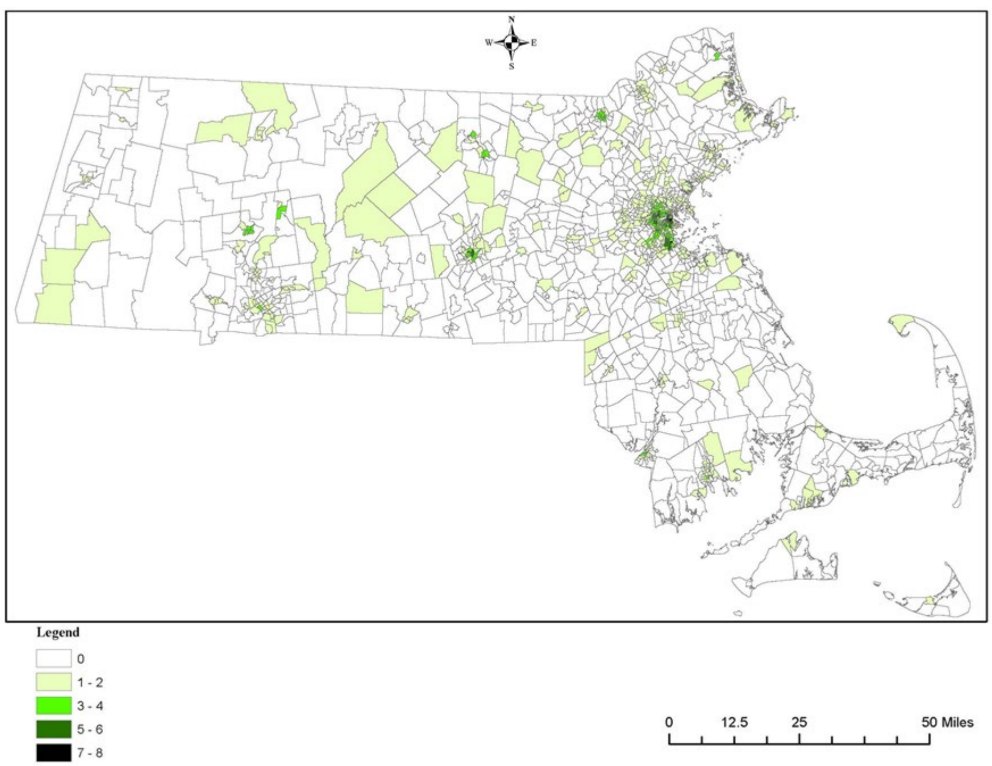


Figure 4.4 Farmers' markets within 1 mile

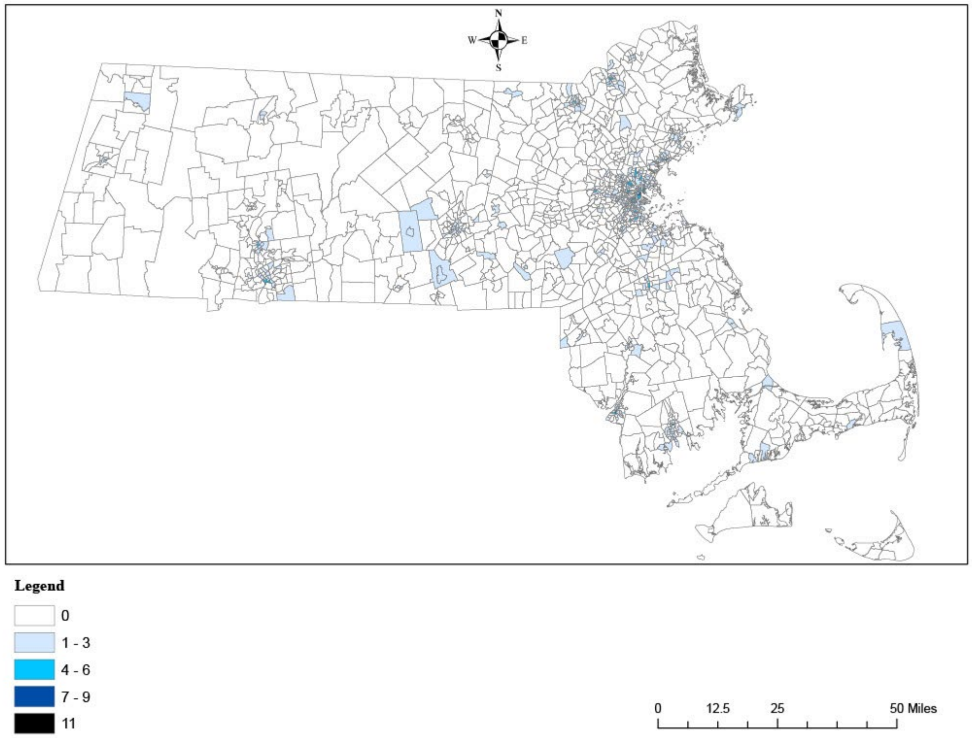


Figure 4.5 Convenience stores within one-quarter mile

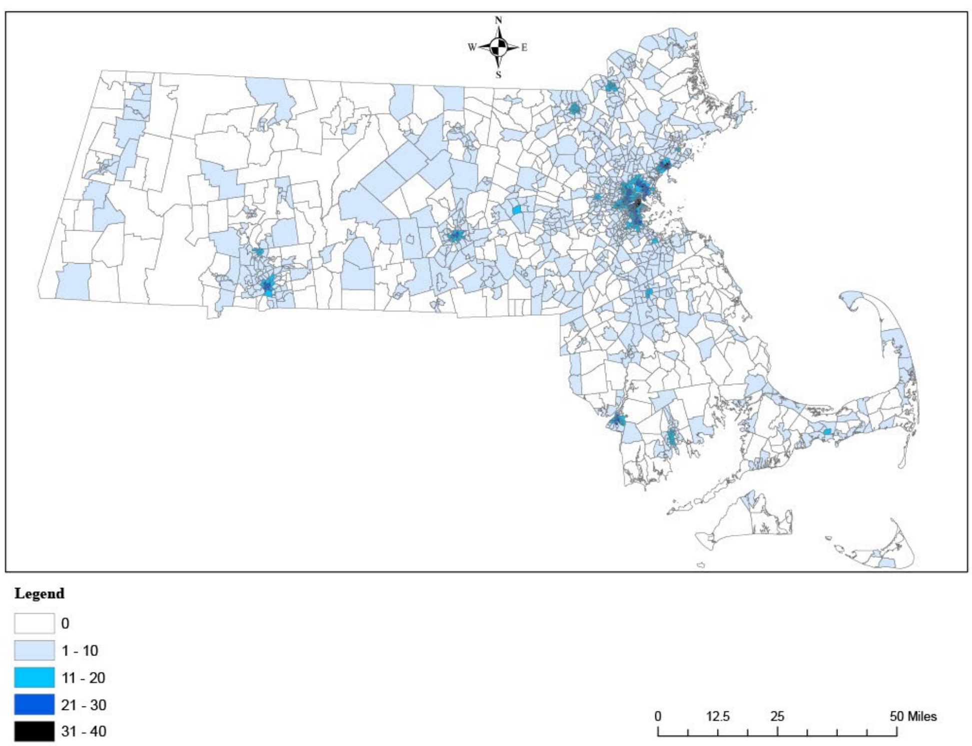


Figure 4.6 Convenience stores within 1 mile

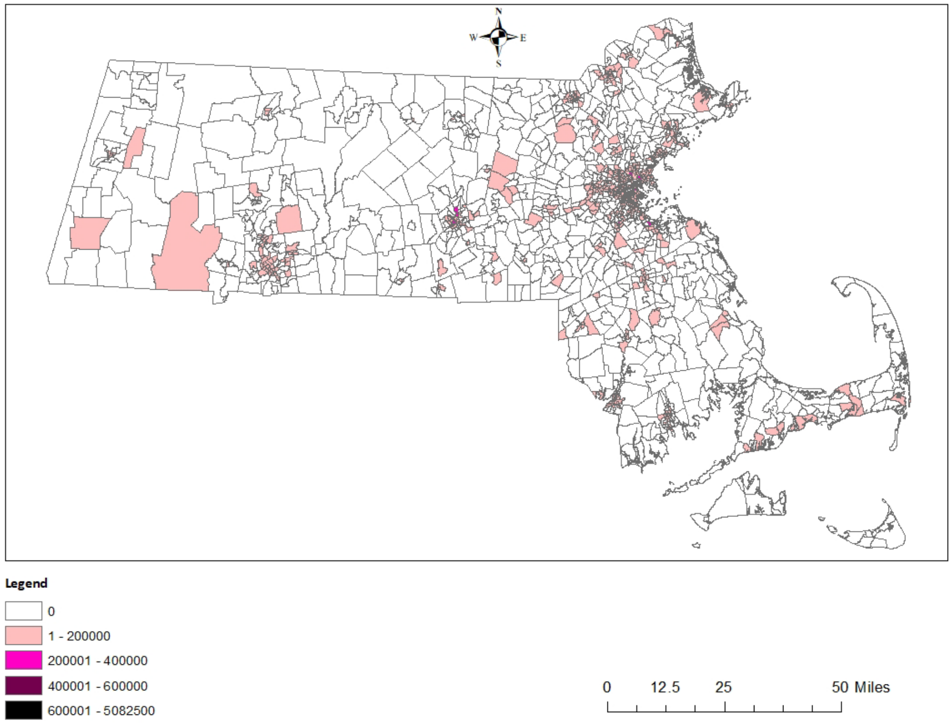


Figure 4.7 Supermarkets (ft^2) within 10 minutes walking

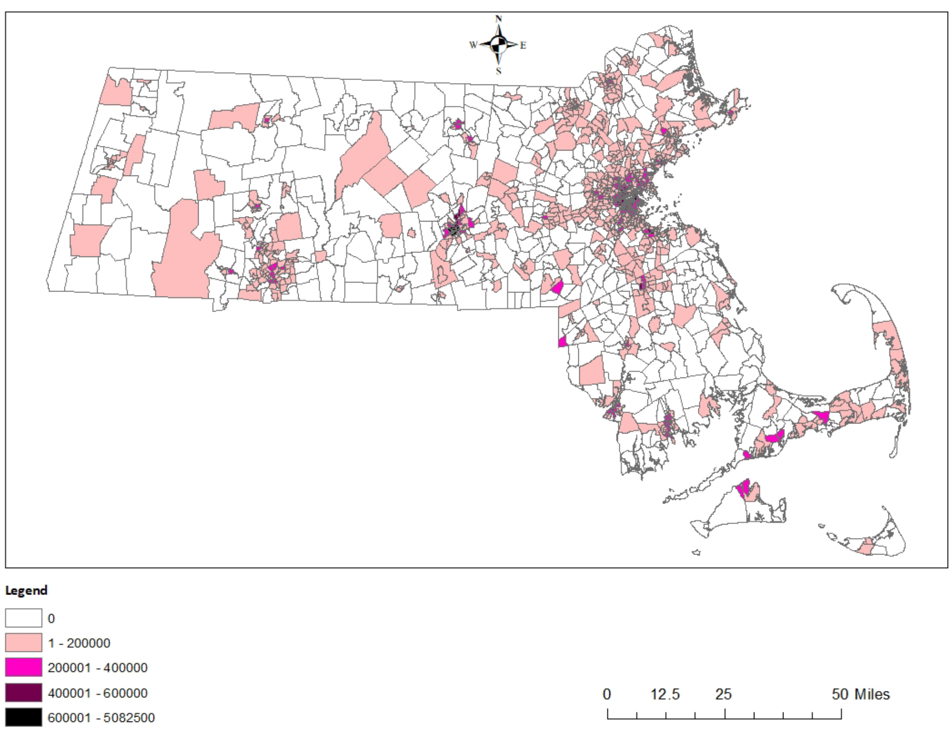


Figure 4.8 Supermarkets (ft^2) within 30 minutes walk/transit

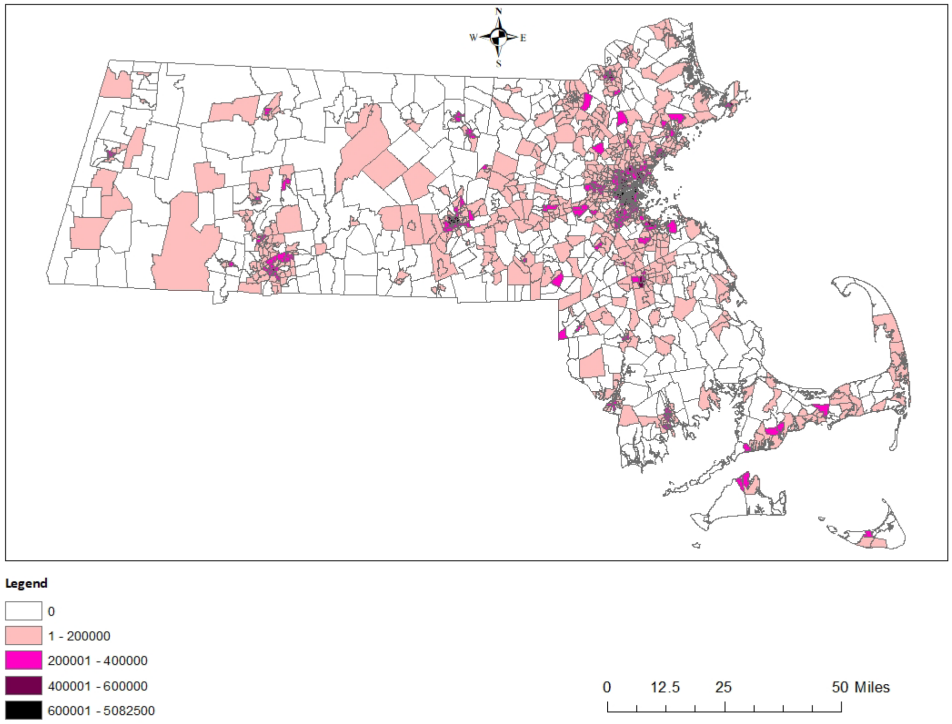


Figure 4.9 Supermarkets (ft^2) within 10 minutes biking

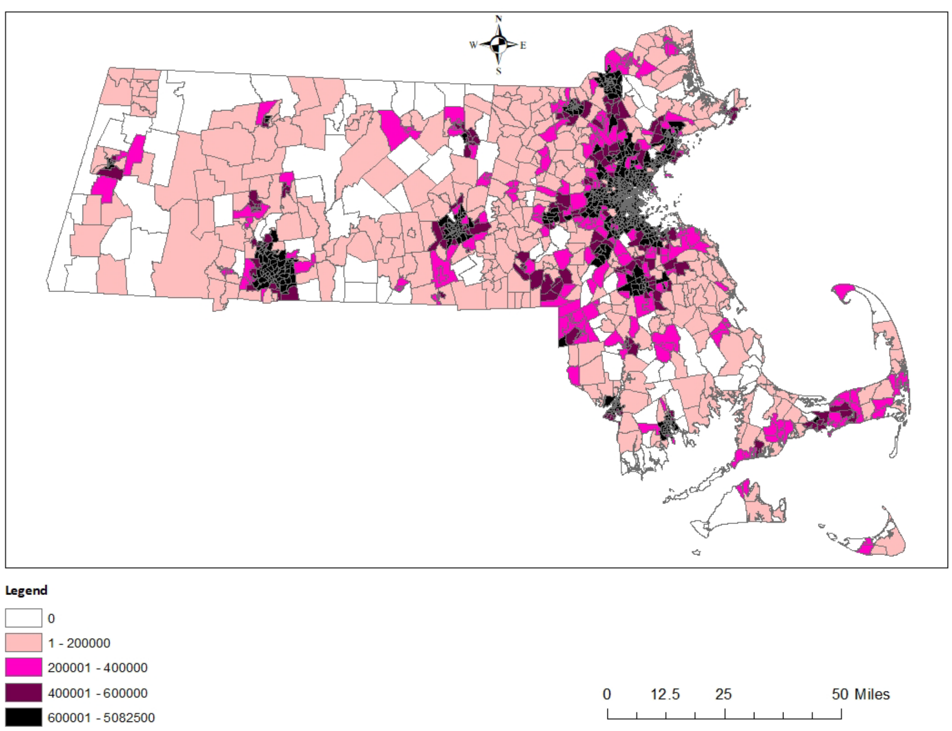


Figure 4.10 Supermarkets (ft^2) within 10 minutes driving

One way to analyze the data involves ranking census tracts from least to greatest measured food access. In the interest of identifying communities with a significant population experiencing low food access, we focus on census tracts with population density exceeding 5,000 people per square mile. Census tracts that have the same observed food access are then ranked in order from greatest to least population density, in order to emphasize communities with more affected residents. Results are compared for the four modes of interest: food access within 10 minutes walking (Table 4.1); 30 minutes walk/transit (Table 4.2); 10 minutes biking (Table 4.3); and 10 minute driving (Table 4.4).

More than half of the census tracts in Massachusetts have no measurable food access within a 10 minute walking trip, as shown in Table 4.1. These communities are generally urban in character and have significantly higher poverty rate and percent minority population than the statewide poverty rate and averages, 11.9% and 13.4%, respectively. This suggests that inequities in food access are a greater burden to minorities and low-income populations. On the other hand, Table 4.4 shows that for food access by driving the census tracts have lower population densities and more varied demographic characteristics. Although some have a higher poverty rate and percent minority population than the statewide average, this is not universal. More affluent communities, which may have low food access, also tend to have higher vehicle ownership rates. Some census tracts with exceptionally low vehicle ownership happen to include significant college and university student populations, and this demographic may experience food access differently than the general public. These census tracts are marked in the tables with notes indicating the corresponding institution. The rankings for walk/transit and biking fall somewhere between the walk access and drive access results. This highlights the difference between food access experienced by people with access to a car versus those who most rely on other modes of transportation. between food access experienced by people with access to a car versus those who most rely on other modes of transportation.

4.2 Equity Analysis Using Lorenz Curves

Lorenz curves have been constructed to show the distribution of food access across Massachusetts as described in Section 3.3. The curves for each of the four transportation modes of interest are plotted in Figure 4.11, showing the cumulative share of total weighted food access (vertical axis) versus the cumulative share of population (horizontal axis). Each of the curves has been scaled to the total weighted food access for the corresponding mode, which are compared in Table 4.5. A related measure is the average food access experienced by a person in Massachusetts, which is calculated by dividing the total food access by the state population. This is also shown in Table 4.5.

If all food access were equal across all census tracts in the state, the Lorenz curve would follow the straight line of equality, because each census tract would contribute the same cumulative weighted food access relative to population. The actual Lorenz curves fall below the line of equality because some residents have lower food access than others. A quantitative measure of the degree of inequality used in this analysis is the Gini coefficient, which is the ratio of the area between the line of equality and the Lorenz curve and the total area under the line of equality. A Gini coefficient of 0 is the most equitable and 1 is the most unequal.

Table 4.1 Lowest food access by 10 min walking (pop. density < 5,000 ppl/mi²)

Census Tract	Town	Food Access (ft^2)				Socioeconomic Variables			
		Walk	W/T	Bike	Drive	Density	Veh/Ppl	Poverty (%)	Minority (%)
25017350700	Cambridge	0	241,250	288,750	1,680,000	18,976	0.54	18.2	11.9
25027732600	Worcester	0	178,750	201,250	2,080,000	15,913	0.49	22.2	14.9
25025130406	Boston	0	7,500	7,500	908,750	15,583	0.44	18.1	51.7
25015820400*	Amherst	0	32,500	33,750	443,750	14,995	0.02	65.5	20.9
25009251400	Lawrence	0	130,000	172,500	897,500	14,946	0.39	19.1	9.8
25025180500	Boston	0	0	1,250	182,500	14,555	0.63	9.4	1.2
25025101002	Boston	0	128,750	212,500	1,431,250	13,684	0.41	19.2	74.7
25021401000	Brookline	0	101,250	445,000	3,383,750	13,637	0.40	10.3	22.2
25017370101	Belmont	0	28,750	145,000	976,250	13,464	0.60	11.7	13.0
25017311500	Lowell	0	45,000	90,000	833,750	13,234	0.68	15.0	42.5

* Census tract includes significant student populations of the University of Massachusetts Amherst.

Table 4.2 Lowest food access by 30 min walking/transit (pop. density < 5,000 ppl/mi²)

Census Tract	Town	Food Access (ft^2)				Socioeconomic Variables			
		Walk	W/T	Bike	Drive	Density	Veh/Ppl	Poverty (%)	Minority (%)
25025180500	Boston	0	0	1,250	182,500	14,555	0.63	9.4	1.2
25013812903	Westfield	0	0	0	295,000	12,402	0.03	0.0	7.0
25025170502	Revere	0	0	1,250	1,297,500	7,061	0.64	15.2	5.8
25009205600	Lynn	0	0	32,500	988,750	6,601	0.56	27.7	13.5
25027732902*	Worcester	0	0	78,750	1,177,500	6,471	0.01	63.6	9.2
25017338200	Winchester	0	0	73,750	193,750	6,174	0.62	5.2	20.9
25017312501	Lowell	0	0	73,750	505,000	5,502	0.65	11.2	12.3
25025130404	Boston	0	0	7,500	383,750	5,438	0.54	5.0	25.2
25023500104	Hull	0	0	1,250	1,250	5,248	0.74	2.7	0.8
25021416200	Boston	0	0	98,750	1,125,000	5,149	0.61	5.8	42.9

* Census tract includes significant student populations of College of the Holy Cross.

Table 4.3 Lowest food access by 10 min biking (pop. density < 5,000 ppl/mi^2)

Census Tract	Town	Food Access (ft^2)				Socioeconomic Variables			
		Walk	W/T	Bike	Drive	Density	Veh/Ppl	Poverty (%)	Minority (%)
25013812903*	Westfield	0	0	0	295,000	12,402	0.03	0.0	7.0
25015821200**	South Hadley	0	0	0	165,000	5,075	0.07	5.8	25.1
25017338100	Winchester	0	0	0	618,750	5,035	0.64	1.0	13.1
25025180500	Boston	0	0	1,250	182,500	14,555	0.63	9.4	1.2
25025170502	Revere	0	0	1,250	1,297,500	7,061	0.64	15.2	5.8
25021417802	Quincy	0	1,250	1,250	498,750	6,941	0.44	28.2	49.9
25023500104	Hull	0	0	1,250	1,250	5,248	0.74	2.7	0.8
25005655200	Fairhaven	0	17,500	2,500	883,750	5,486	0.61	8.4	11.1
25021402200	Boston	0	0	2,500	678,750	5,093	0.69	3.3	11.2
25017310602	Lowell	1,250	1,250	3,750	328,750	5,280	0.62	17.8	23.1

* Census tract includes significant student populations of Westfield State University.
** Census tract includes significant student populations of Mount Holyoke College.

Table 4.4 Lowest food access by 10 min driving (pop. density < 5,000 ppl/mi^2)

Census Tract	Town	Food Access (ft^2)				Socioeconomic Variables			
		Walk	W/T	Bike	Drive	Density	Veh/Ppl	Poverty (%)	Minority (%)
25023500104	Hull	0	0	1,250	1,250	5,248	0.74	2.7	0.8
25009203302	Marblehead	0	102,500	106,250	107,500	5,172	0.69	6.2	1.7
25023561200*	Bridgewater	71,250	141,250	141,250	141,250	7,537	0.09	41.2	15.7
25017382601	Sherborn	0	77,500	77,500	156,250	6,580	0.69	4.4	44.2
25015821200**	South Hadley	0	0	0	165,000	5,075	0.07	5.8	25.1
25025180500	Boston	0	0	1,250	182,500	14,555	0.63	9.4	1.2
25017370201	Belmont	0	3,750	11,250	192,500	7,546	0.68	5.4	9.7
25017338200	Winchester	0	0	73,750	193,750	6,174	0.62	5.2	20.9
25009203301	Marblehead	0	107,500	107,500	200,000	5,659	0.74	7.6	2.4
25027716300	Clinton	25,000	105,000	105,000	202,500	5,395	0.65	12.3	3.6

* Census tract includes significant student populations of Bridgewater State University.
** Census tract includes significant student populations of Mount Holyoke College.

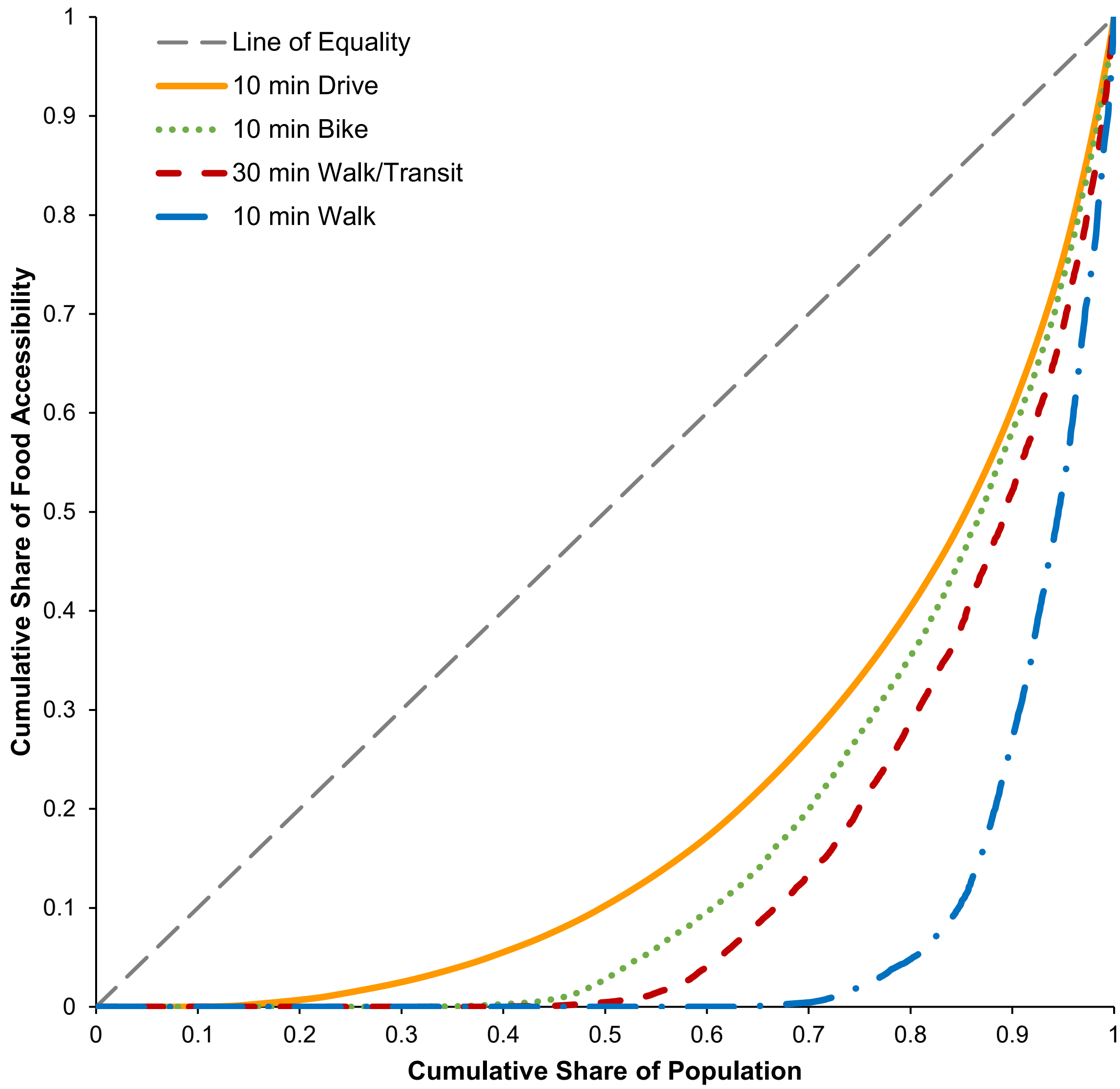


Figure 4.11 Lorenz curve showing distribution of food access

Table 4.5 Comparison of food access by transportation mode

Mode	Food Access		Gini coefficient
	Total (10^9 ppl·ft^2)	Average (ft^2)	
10 minutes walking	128	18,668	0.857
30 minutes walk/transit	656	96,095	0.718
10 minutes biking	928	135,862	0.659
10 minutes driving	5,260	770,086	0.582

Not only does driving provide the most food access in aggregate (Table 4.5), Figure 4.11 reveals that food access by driving is more equitable than by any other mode, because the Gini coefficient of 0.582 is lowest, and the corresponding curve lies above all others. Suburban and rural communities typically have at least some supermarkets within a 10 minute drive of most residents and development patterns are usually designed for people to access supermarkets by car. In contrast, food access by walking is the least equitable, because only dense urban neighborhoods have significant populations within walking distance of supermarkets. Furthermore, only 50% of the population has access to food within 30 minutes by transit. The lower total weighted food access and the higher Gini coefficients for nondriving modes highlight the significant food access disadvantage for people without access to a car.

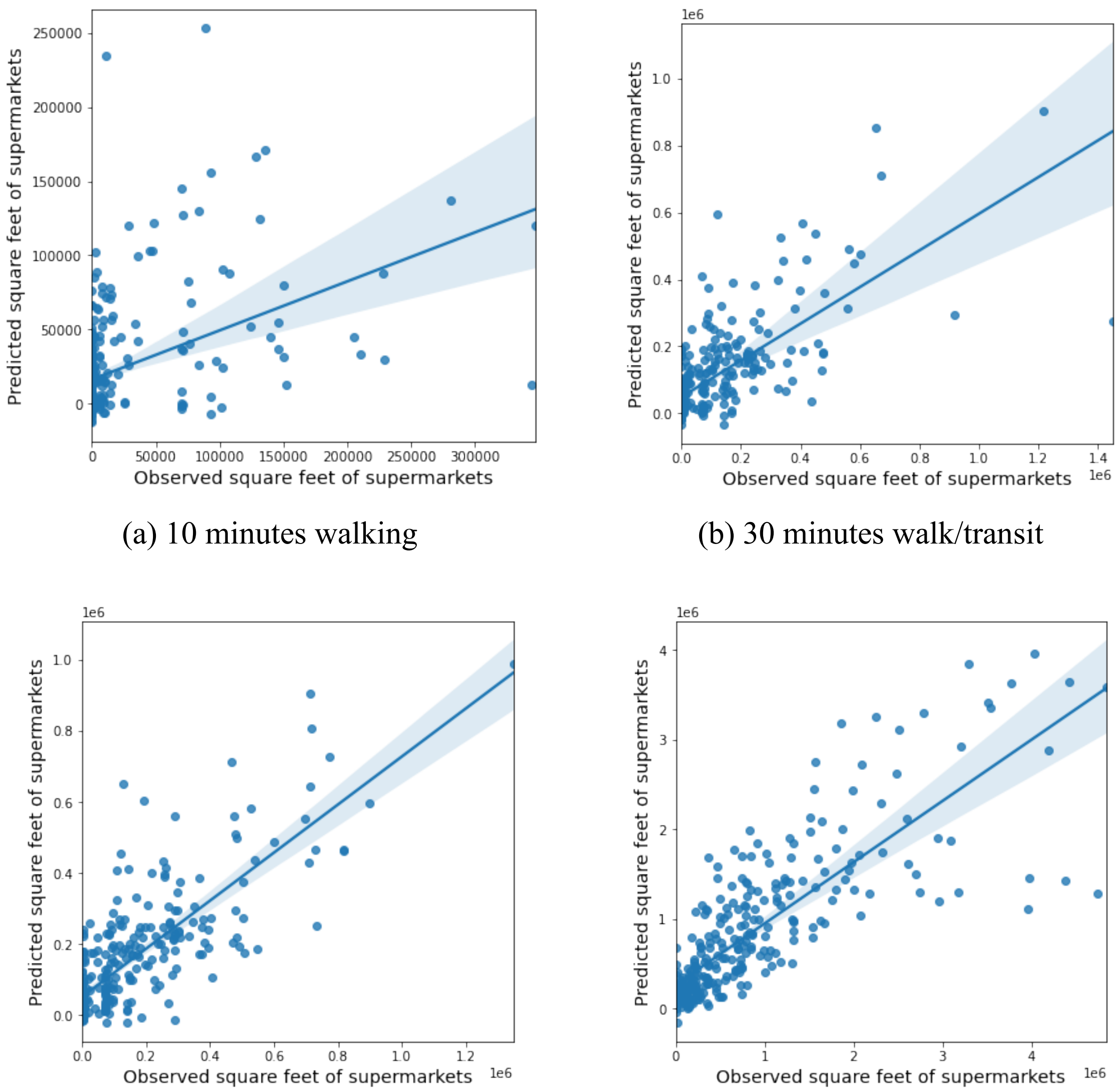
4.3 Machine Learning

Having quantified food access for communities across Massachusetts and identifying inequities based on transportation mode, the next step is to identify specific food access gaps. For this, models are developed using GBM for each of the four modes. These models are evaluated based on the Mean Absolute Error (MAE) and RMSE applied to the test data as shown in Table 4.6. The MAE is the average difference between the predicted and observed values, and the RMSE is the square root of the average squared error, which is what GBM seeks to minimize with the training data.

Table 4.6 Supermarket access model errors (ft^2)

Model	MAE	RMSE
10 minutes walking	24,769	48,343
30 minutes walk/transit	73,062	129,015
10 minutes biking	80,405	120,726
10 minutes driving	360,435	577,088

All the MAE and RMSE values are consistent with good fit as shown in Figure 4.12 for four transportation modes. For 10 minutes walking, the fit is reasonable because most of the census tracts have either a small number of supermarkets or none at all. Most of the observations and predictions for food access by walk/transit or biking are related to larger supermarkets compared to walking yet the total accessible area of supermarkets is less than 300,000 ft^2. The concentration of points along the line shows a fit that is particularly good for driving.

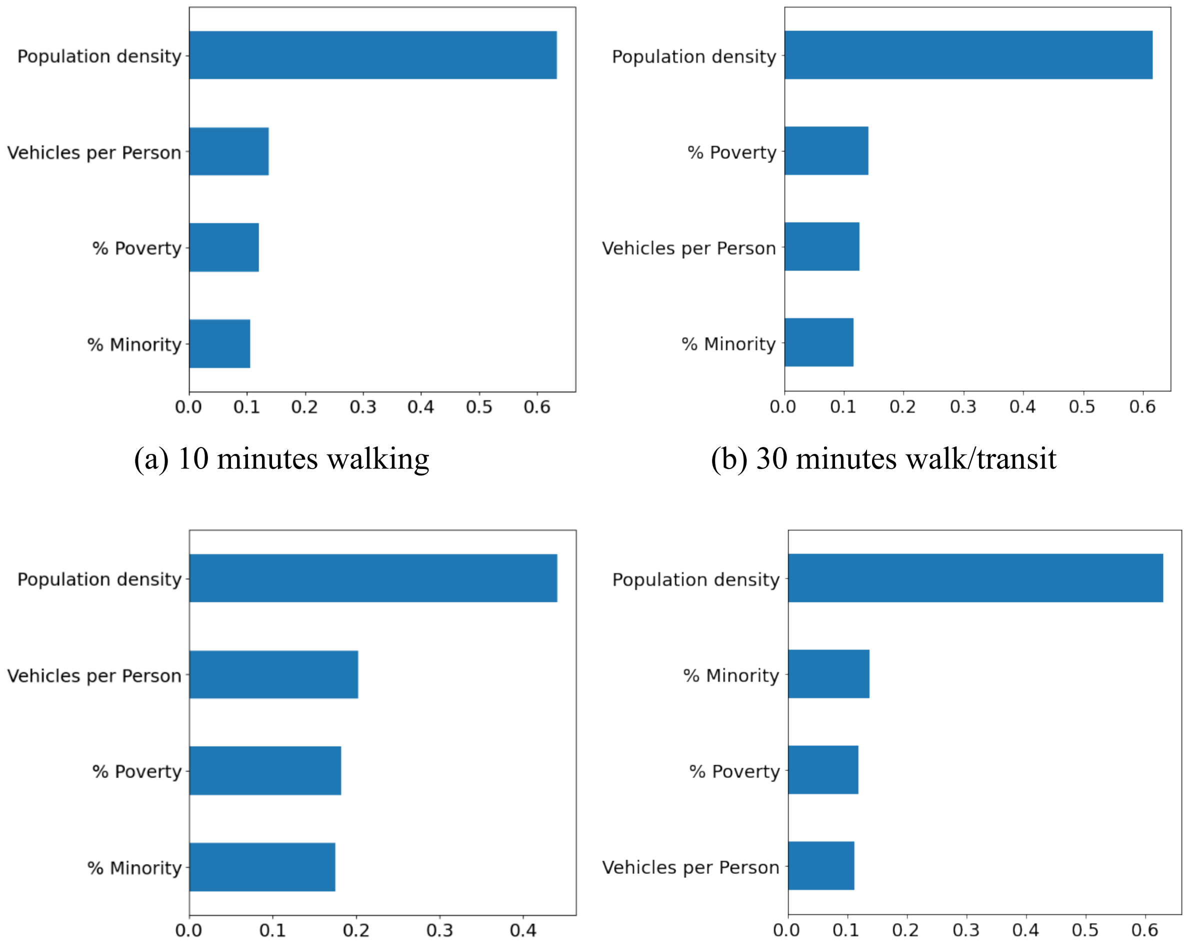


(a) 10 minutes walking (b) 30 minutes walk/transit

(c) 10 minutes biking (d) 10 minutes driving

Figure 4.12 GBM prediction of food access versus observation

A useful aspect of the GBM analysis is that the importance of each of the explanatory variables is quantified, as shown in Figure 4.13. As expected, population density is the most important variable for all cases, because larger populations support more supermarkets. The other socioeconomic variables are less important and vary slightly from one mode to another. Vehicle ownership is the second most important for walking and biking because census tracts with high food access by nonmotorized modes tend to be walkable urban communities where the need for car ownership is lower. The poverty rate is an important determinant of public transit use for food access, as demonstrated in Figure 4.13b. The percent minority population is of greater importance for the driving mode, because there are also significant minority populations in suburban parts of the state where supermarkets and parking lots more common (Figure 4.13d).

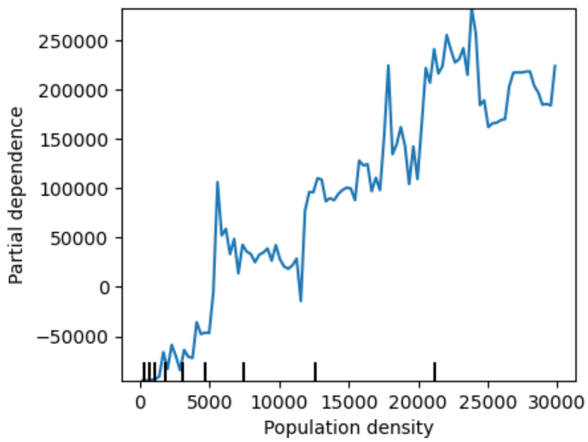


(a) 10 minutes walking (b) 30 minutes walk/transit

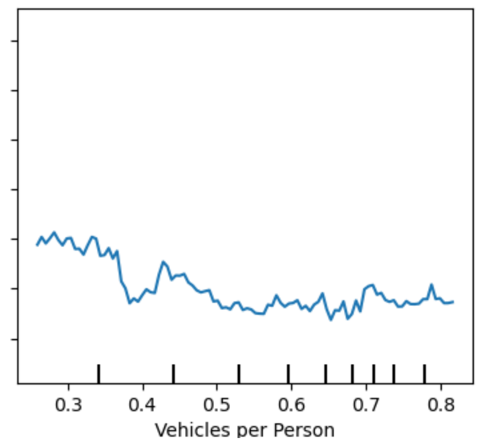
(c) 10 minutes biking (d) 10 minutes driving

Figure 4.13 Variable importance plots of the GBMs

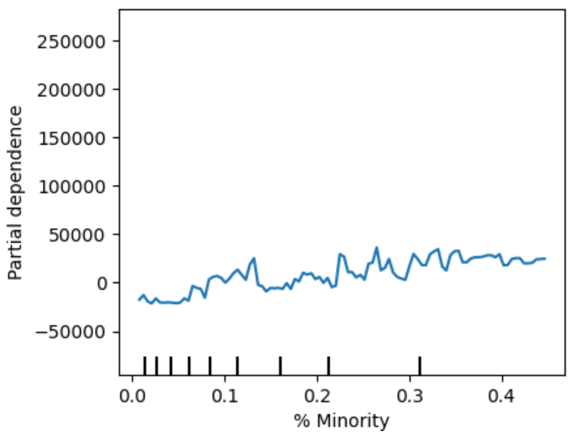
Another way to look at the GBM results is through partial dependence plots, which show the relationship between food access and each of the socioeconomic explanatory variables, as shown in Figure 4.14 for access by walk/transit. The vertical axis represents the magnitude of the effect (either positive or negative) that each factor has on food access as the factor value increases along the horizontal axis. As the population density increases, the total square footage of supermarkets within 30 minutes walk/transit increases as well. The vehicle ownership plot shows that higher values of vehicle ownership are related to smaller grocery store total square footage, which reflects the fact that vehicle ownership is higher in suburban and rural areas where supermarkets are more dispersed. Furthermore, the minority population percentage and percentage below the poverty line do not have a strong effect on the predictor, as the value remains relatively steady across all values of these socioeconomic factors. The only notable exception is census tracts with more than 20% of the population living in poverty, which saw sharp increases in the predictor variable. This reflects the fact that the most impoverished communities in Massachusetts are in urban areas where there are also more supermarkets. Similar patterns exist for access by walking, biking, and driving.



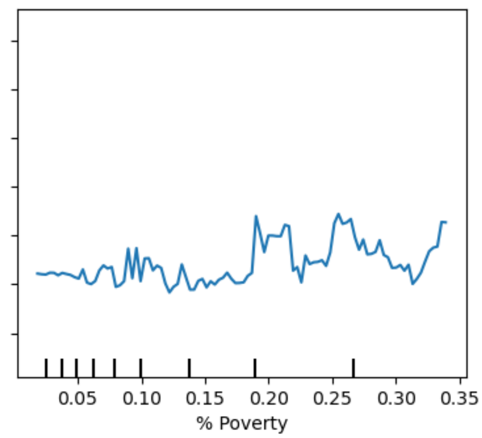
(a) Population Density



(b) 30 Vehicles/Person



(c) Minority (%)



(d) Poverty (%)

Figure 4.14 Partial dependence (GBM) for 30 minutes walk/transit access

The GBM is implemented with multiple iterations so that the effect of random variations in machine learning parameters can be quantified. The coefficient of variation (CV) is the standard deviation of predicted values over the mean value of the GBM estimates. A low CV represents greater consistency in model predictions, which indicates greater confidence in the accuracy of predictions. In this study, twenty iterations of the GBM are run for each of the four models, and the CV for each model are shown in Figure 4.15 through Figure 4.18. Figure 4.18 shows that driving has the lowest CV statewide, which is due in part to the fact that a larger square footage of supermarkets can be accessed within 10 minutes by car than any other mode.

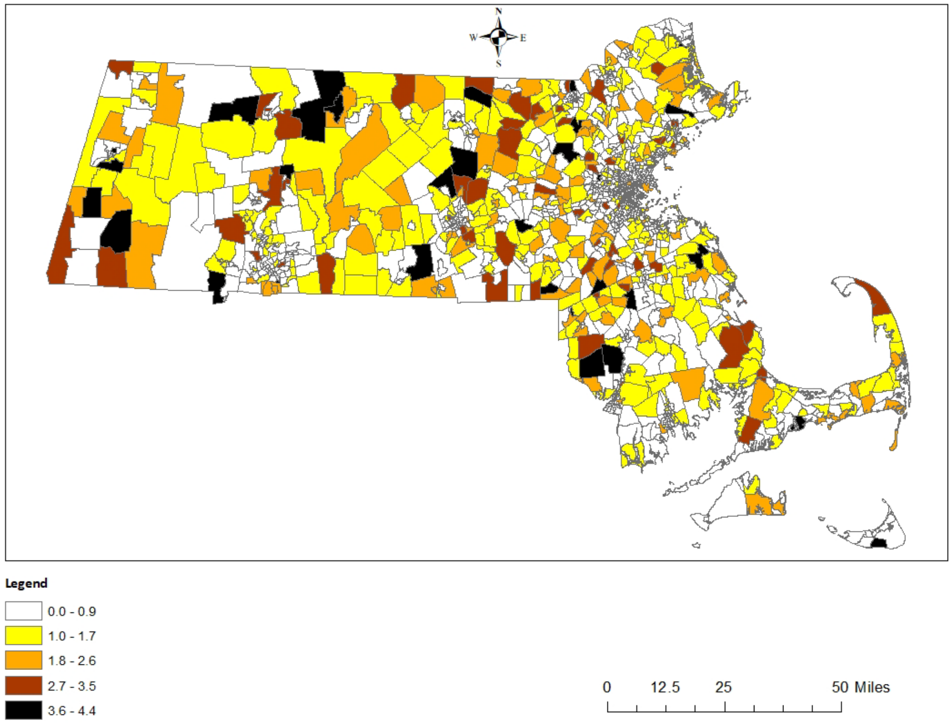


Figure 4.15 CV for 10 minutes walking

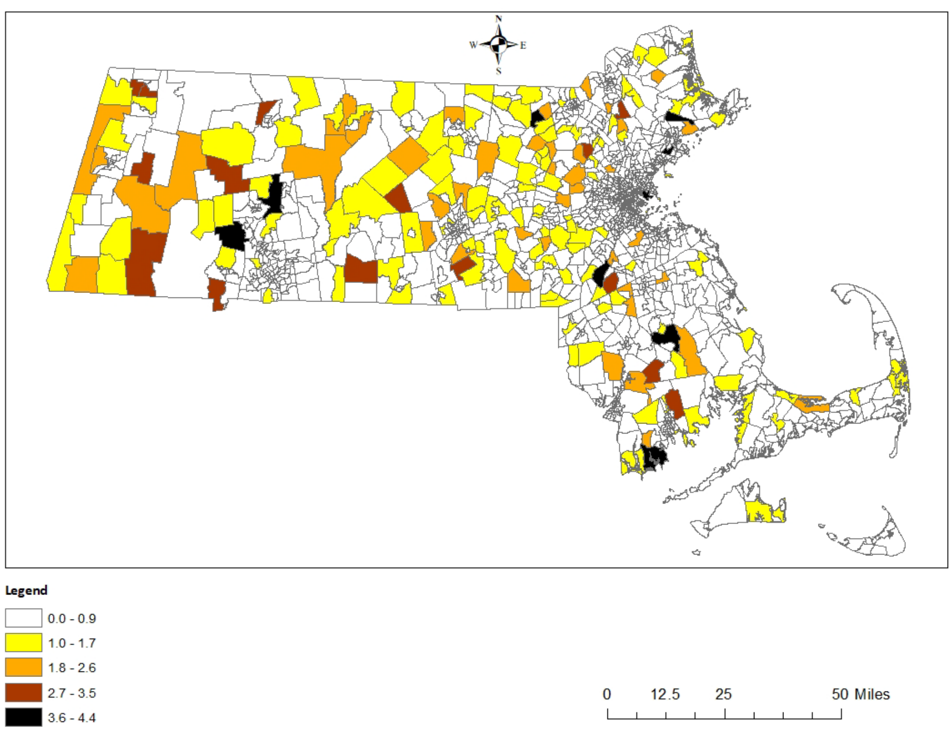


Figure 4.16 CV for 30 minutes walk/transit

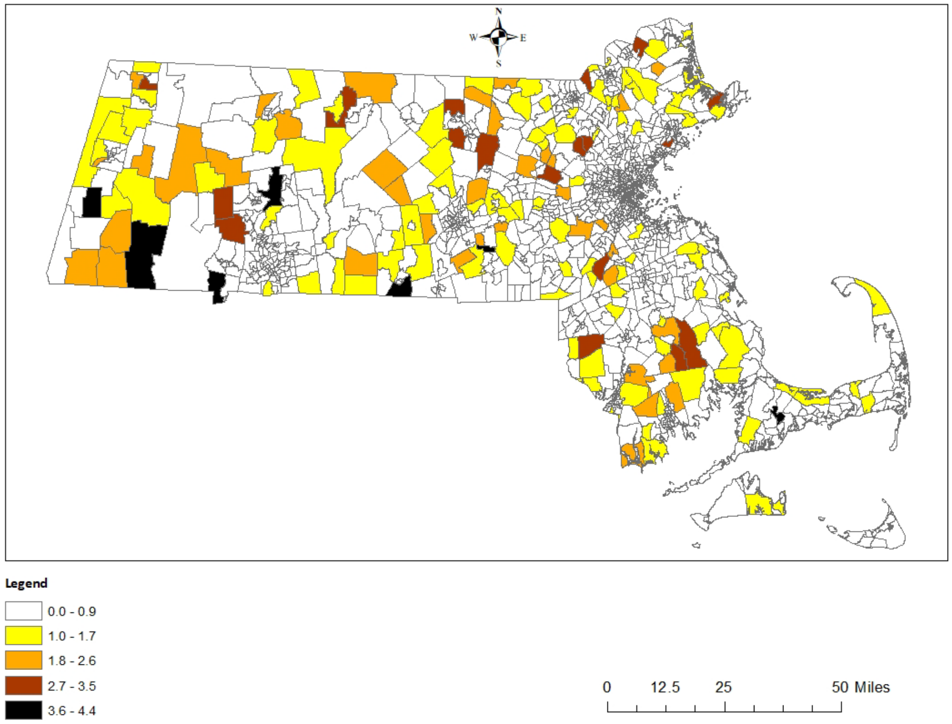


Figure 4.17 CV for 10 minutes biking

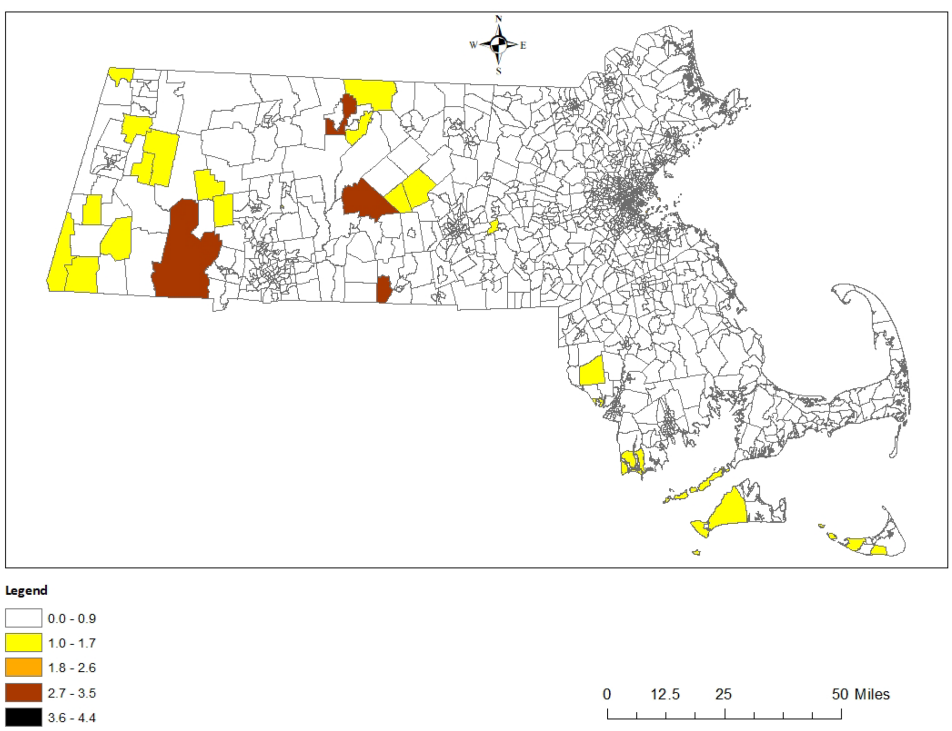


Figure 4.18 CV for 10 minutes driving

The most useful way to interpret the results of the GBM is to look at the difference between the observed and predicted food access in each census tract, which is the residual of the model. Without additional constraints the GBM can predict negative values for food access, which is not physically possible, so predictions are bounded to be non-negative. The ratio of this bounded residual to the mean predicted food access is the relative error, δ, that reveals the difference between the observed food access, FA_o, and the predicted food access, FA_p.

$$\delta = \frac{FA_o - \min\{FA_p, 0\}}{\min\{FA_p, 0\}} \tag{1}$$

The relative error, defined this way, is more useful than the absolute error for making relative comparisons across Massachusetts, because absolute errors tend to be larger in more urban census tracts where food access is generally much higher. The lighter pink color in Figure 4.19 through Figure 4.22 represents negative errors in which the observed food access is less than the prediction, based on statewide data. The darker blue color represents areas with relatively higher food access. Figure 4.19 shows the limited food access by walking across most of Massachusetts, which becomes better when using transit (Figure 4.20) or bike (Figure 4.21). By driving, food access gaps are fewer, but Figure 4.22 shows that they appear in all parts of the state.

4.4 Focus Groups

The research team conducted two of the three originally planned focus groups due to inability to find a common time for the Worcester stakeholders within a reasonable timeframe. As a result, this section presents only the results of the focus groups with Amherst and Deerfield.

4.4.1 Amherst Focus Group

Four individuals representing three organizations, namely the Pioneer Valley Transit Authority (PVTA), Health Hampshire and Mass in Motion, and the Amherst Survival Center participated in this focus group on March 30, 2023.

The participants discussed challenges with defining food access given its multiple dimensions, including presence of grocery stores and food retailers in general also in addition to the level of affordability and presence of culturally appropriate food options.

The discussion also revealed that the lack of grocery stores within the town of Amherst places the vast majority of the population in a food desert. Amherst not only lacks access to larger grocery stores but also to smaller markets. Additionally, the closest grocery stores do not necessarily provide culturally appropriate foods that are available at locations that are hard to reach with the available transit service.

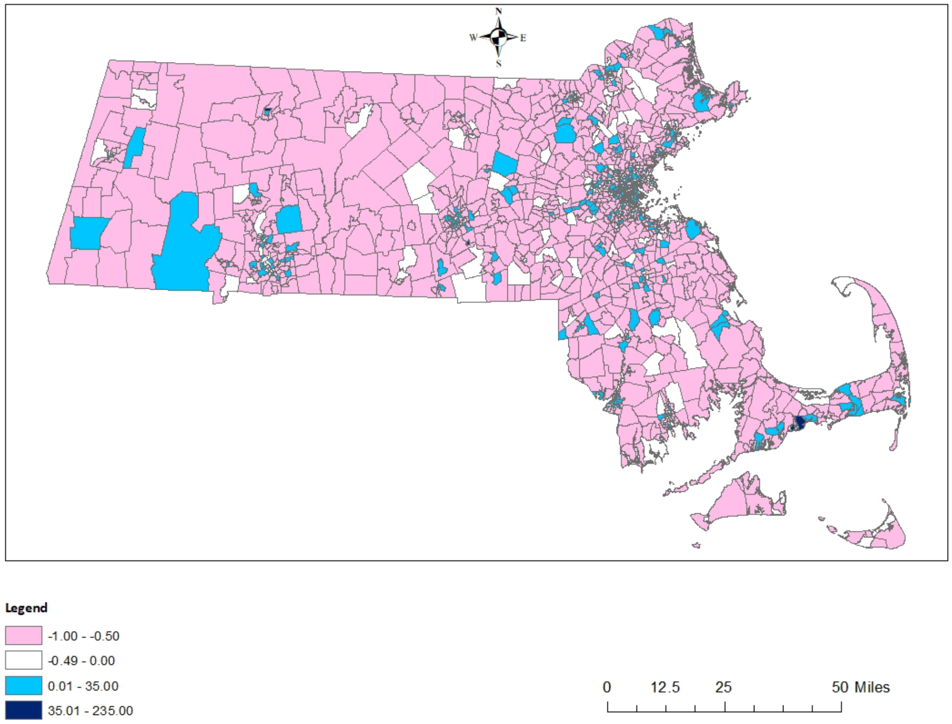


Figure 4.19 Relative error for 10 minutes walking

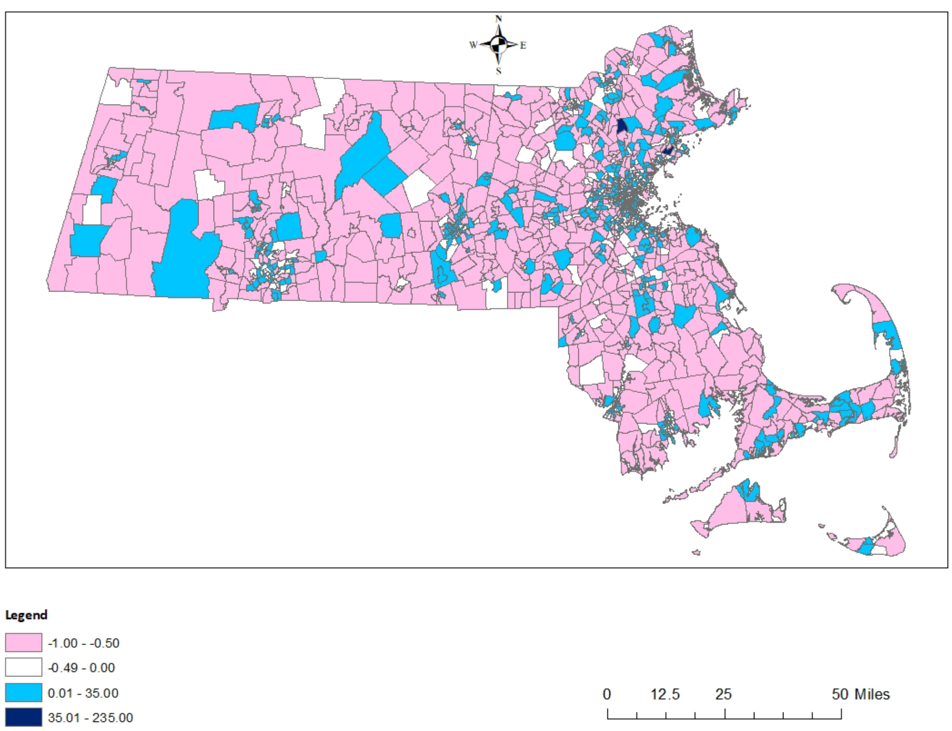


Figure 4.20 Relative error for 30 minutes walk/transit

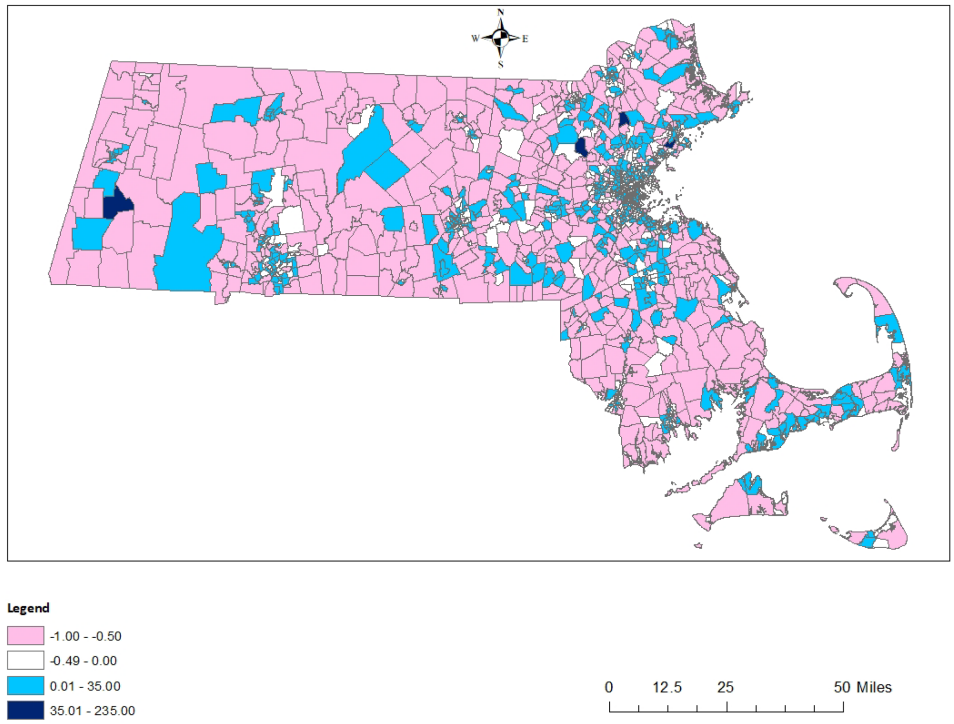


Figure 4.21 Relative error for 10 minutes biking

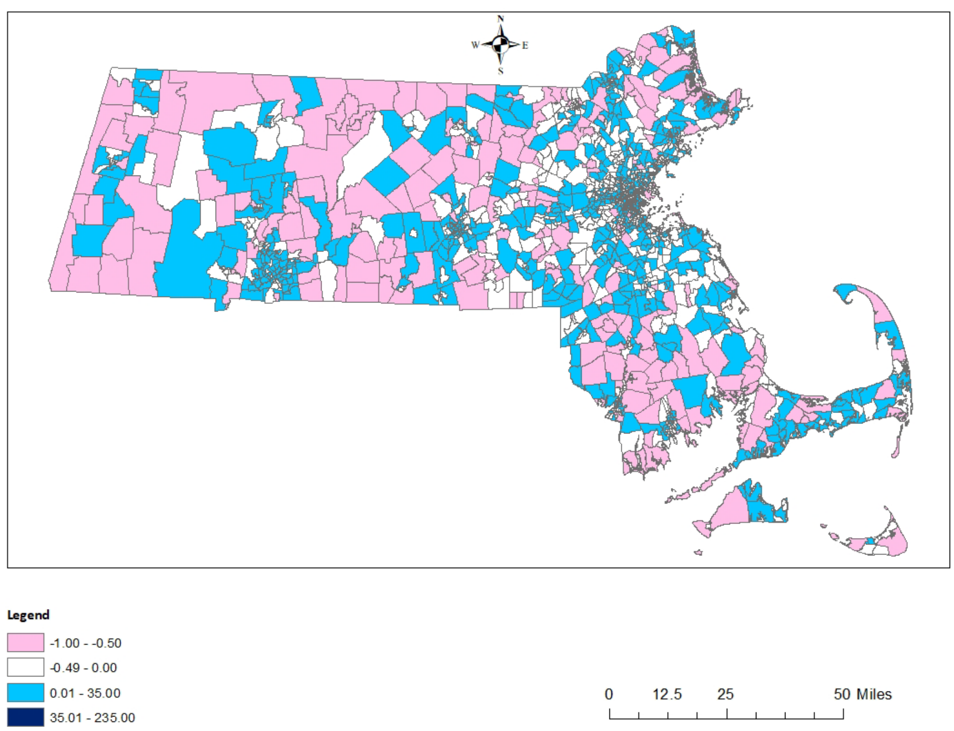


Figure 4.22 Relative error for 10 minutes driving

The low density and relative absence of affordable housing acts as an additional barrier to connecting certain, already disadvantaged neighborhoods, with food retailers through public transportation. Limited shared mobility options such as taxis and transportation network companies in Amherst further limit food access options for car-free households. South Amherst was reported to be the area of highest concern primarily due to high concentration of racial minority populations and low-income individuals as well as a large number of affordable housing units, many of which are located in areas with low food access. Overall, the focus group participants agreed that land use plays a significant role in exacerbating the lack of access to food in Amherst, primarily affecting those with mobility challenges (e.g., no or limited access to a car, people with disabilities, and single mothers).

While town residents are grateful for the free transit service funded by the Five Colleges, and the communication of PVTA's schedule, challenges persist with accessing food using transit:

1. Long and unreliable travel times to grocery stores or food banks, often requiring transfers, which not only limits access but also raise concerns about food spoiling;

2. Lack of transit connections to culturally appropriate foods, as those retailers are not accessible by existing transit lines;

3. Infrequent and irregular (i.e., year-round) transit schedule that is based on the academic calendar, which further restricts food access especially during holidays;

4. Lack of infrastructure to access and wait at transit stops, including lack of sidewalks, crosswalks, paved spaces to wait, benches, shelters, and lighting; and

5. Restrictions on the number of bags one can carry on the bus, which limits the amount of food an individual can take from the Amherst Survival Center or other food banks.

Many of these issues have been the result of historical practices and the disconnect between land use and transportation. In Amherst specifically, these have been exaggerated due to the presence of the University, which has led to a hub-and-spoke structured transit system.

The PVTA has initiated studies that are investigating inequities in accessibility in the Pioneer Valley that will result in some guidance regarding necessary transit system improvements. It was also acknowledged that funding can be a barrier to those improvements especially in jurisdictions such as Amherst where changes need to be approved by multiple stakeholders and funded by the Five Colleges.

While alternative modes such as the ValleyBike bike share system can provide some access, it cannot be seen as viable option for solving food access inequities. Undocumented immigrants and others working multiple jobs require transportation options that are faster than biking. In addition, individuals with disabilities or seniors cannot always use them or carry food while using them. Food delivery could be another option but remains costly and has limitations on the use of SNAP for certain online orders.

Other options that have been put in place to improve food access for equity-focused populations are Healthy Hampsire's mobile market, which visits the East Hadley Road neighborhood once a week and Amherst Survival Center's visits to some neighborhoods a few times per week.

Food-related improvements could include

1. More numerous and affordable grocery stores in Amherst (The focus group participants recognize, however, the challenge in doing so given existing zoning ordinances and grocery store saturation in Hadley, Massachusetts, close to the town's boundary.);

2. Creation of additional food pantries and mobile markets; and

3. Establishment of supplemental income programs.

Transportation-related improvements could include

1. Introducing a regular circulating bus that connects the grocery stores in Hadley with communities in need, and which people can rely on all year-round;

2. Higher frequency bus service with regular schedule year-round; and

3. Improved infrastructure and lighting for accessing and waiting at bus stops.

All of the transportation-related interventions require funding, which could be challenging in this area, given the buy-in required by the Five Colleges, and also due to the transit service in Amherst being operated by primarily UMass students that limits labor availability in the summer months.

4.4.2 Deerfield Focus Group

Six individuals representing four organizations, namely the Franklin Regional Transit Authority (FRTA), the Franklin Regional Council of Governments, the Community Care Coalition and Mass in Motion, and the South County Senior Center participated in this focus group, which took place on March 28, 2023.

In agreement with the Amherst focus group, the participants talked about the multidimensionality of food access inequities, which cannot be described by just a single metric. Food access needs to be accessed not only based on the number of stores that can be accessed, but also on the variety and affordability of foods that is available at the accessible food retailers. Deerfield is a food desert since there is not equitable access for everyone that needs it. In addition, food which is accessible in Deerfield often comes from local farm stands, which are not open year-round and are hard to measure.

Access to food appears to be worse in the Hilltowns, and specifically in West Deerfield, west of I-91. This is due to the northern and southern parts of Deerfield having access to Greenfield and Hadley respectively. The young and the seniors, who are characterized by limited budget and access to transportation, in addition to farm workers that often have limited English proficiency, tend to be the most disadvantaged in terms of food access within the Franklin County.

Provision of transit services, both fixed route and microtransit (demand response), has been beneficial for the area, especially in facilitating access to grocery stores. Unfortunately, accessible grocery stores are limited and therefore, do not necessarily meet the population's needs and are expensive resulting in inequitable food access. In addition, there are no food pantries within Deerfield. residents either have to visit their closest one which is the Amherst Survival Center requiring use of bus service from two regional transit authorities (FRTA and PVTA) or the one in Greenfield through the FRTA transit system. The fact that Deerfield is on the edge of Franklin County in combination with the limited overlap between the FRTA and PVTA transit networks further inhibits food access that could be achieved by traveling to locations in the adjacent county.

Several programs have been implemented that support improved food access. On the transportation side, the Access microtransit program is an on-demand transit service for a fare of \$3 within one zone (one way) and \$4 across zones (one way). The program has been well-received and is often preferred to the fixed route buses despite its higher fare. Grocery stores are the number one destination for the Access program vehicles, although it may be possible that some users work at grocery stores, i.e., they use the Access program for their trip to work rather than for food access.

Other efforts that are being implemented to address food access inequities are the South County Senior Center's pop-up pantries (on the second Wednesday of each month), which take place in the Franklin County Survival Center. In addition, the South County Senior Center offers a brown bag program for seniors and a van used to deliver food from the pop-up market for those without transportation access to food retailers regardless of age. Through their Mass in Motion partnership and in collaboration with a volunteer organization, Valley Neighbors, they also coordinate rides with volunteers that take seniors to grocery stores. The South County Senior Center is also planning to partner with Valley Neighbors to procure a van from the MassDOT Community Transit Grant Program, which can cover the majority of the cost for the van procurement. Mobile markets are also offered by one of the large grocery stores in the area and that accept both SNAP and HIP benefits. One of the primary challenges programs face is communication of information about program benefits and reaching all eligible individuals. This is particularly difficult in rural communities that have more dispersed populations.

Food insecurity is a significant problem in schools in Franklin County, especially during vacation weeks. In the summer, Project Bread provides daily food options for students, but during other school vacation food access programs are limited. Massachusetts House Lawmakers have proposed a bill H.603, An Act Relative to Universal School Meals, to make free school meals permanent for all students in the state, which could address some of these concerns.

On the transportation side, improvements to the bicycle and pedestrian network are needed, particularly those that provided linkages to public transportation routes. Electric bikes are becoming more popular due to their range and ease of getting around especially in rural and hilly areas. Like Amherst, Deerfield is also a rideshare (e.g., taxis, transportation network companies) desert. Food delivery options are minimal, available only through a few retailers and cover primarily the South Deerfield area. In addition, food delivery is expensive.

Food-related improvements could include the following:

1. Increase the number of HIP-authorized HIP vendors, spread them out and/or more collectively have whole farmers' markets being HIP-authorized (e.g., Montague);
2. Close the SNAP gap, i.e., making sure that individuals that are eligible are enrolled and know how and where to use their SNAP and HIP benefits;
3. Remove food delivery cost for SNAP users as during COVID;
4. Address food storage issues related to schools and other organizations and encourage collaborations with other institutions that serve food to operate more efficiently; and
5. Address food insecurity in schools by providing food during school vacations.

Transportation-related improvements could include the following:

1. Walk and bike network investments to improve the first/last mile access to transit;
2. Expand microtransit and paratransit services;
3. More frequent transit service with a wider service span (earlier or later in the day, weekend service) and cheaper fares;
4. Work with towns to encourage collaboration between transit agencies to ensure better integration of service across county/regional transit authority boundaries and provide access to areas with multiple food options (e.g., Hadley);
5. Adjust federal regulations to allow vans obtained through federal programs to be used for food outside of times which vehicles would be used for passenger transportation. This has been allowed during COVID for incidental use after a prior-authorization with the limitation that transporting food cannot take the place of passengers (i.e., restricted to hours when the vehicle is not otherwise in use). This policy could be expanded to include food access during otherwise scheduled passenger transportation operation hours; and
6. Policy changes to allow vehicles (e.g., vans and school buses) to be used for other purposes in conjunction with scheduled passenger transportation.

With discussion of policies like a carbon tax and east–west rail in Massachusetts, new revenues could be used to support transportation needs within the more rural communities of Western Massachusetts. For example, subsidies could attract more rideshare drivers or funding could support expansion of transit service.

5 Recommendations

The analyses conducted as part of this study are designed to identify accessibility gaps in Massachusetts that could be addressed with policies or investments. In this section, recommendations are made based on the findings from the results reported above. First, statewide data analysis provides a method for measuring food access that can be used for quantitative benchmarking and comparisons. Then, policies and investments that address the spatial dimension of food access are presented. This includes methods to move food to the people who need it as well as methods to move people to where the food is available for them. Finally, some comments on general policies or regulations that related to transportation and food accessibility are discussed.

5.1 Measuring Food Access

In order to improve food access in Massachusetts, it is first necessary to determine the appropriate metrics that can be compared across locations, across modes, and tracked over time. The definition of food access proposed and adopted in this study is the square footage of supermarkets that are accessible within a travel time constraint of a specific point (e.g., the centroid of a census tract). This provides a quantitative and objective measure based on data that can be updated in response to changes in the locations and sizes of supermarkets as well as changes to the transportation network.

5.1.1 Tracking Food Access Within a Community

The main building block of the analyses in this study is the measure of food access described in Section 3.2.2 and Section 4.1.

Recommendation 1: Track food access in a census tract by travel time constraint

Within a specific community, there is value in tracking the measured food access across modes to get a sense of degree to which lack of access to a car imposes a barrier to food access. For this purpose, we recommend measuring food access by the four modes used in this study, with travel time constraints that reflect the true time spent on transit when making these trips (i.e., 10 minutes walking, 10 minutes biking, 30 minutes walk/transit, 10 minutes driving). One important change to the analysis methods presented in this study are that microtransit services should be accounted for as part of the transit mode so that the effect of these services is accurately represented.

The emphasis on nonmotorized modes, such as walking, biking, and public transportation services, provides insights about the options available to people who do not have access to a car. Large differences between the food access by these modes would be an indication of an inequity for some users.

Food access in a community should also be tracked over time, documenting changes in supermarket locations and the transportation network. By using the same metric over time, existing food access serves as a benchmark for measuring changes in food access that result from investments in the transportation system, changes in food retailers, or demographic shifts. Tracking progress over time has the benefit of comparing a community within its specific local context rather than other communities, which may have different characteristics.

5.1.2 Statewide Metrics of Food Access

Stepping back from the analysis of individual census tracts, the food access data can also be viewed in aggregate at the statewide level. Using the methods from the equity analysis presented in Section 3.3 and Section 4.2, the food access data from each of the 1,472 census tracts in Massachusetts viewed together.

Recommendation 2: Measure average statewide food accessibility

One cumulative measure of food accessibility is the average food access as experienced by the population of Massachusetts. This value is calculated by summing the population-weighted food access across all census tracts and dividing by the total population of the state and can be done for any food access metric. The average statewide food access is a more useful measure than total weighted food access, because it accounts for the size of the population. This metric can be compared across modes to understand how total food access varies depending on the modes available to a particular modal user. It can also be used to track statewide changes in food access over time. These changes could be in response to transportation investments (e.g., increases in transit service), housing and land use policies (e.g., whether affordable housing is developed in food-accessible locations), or demographic changes (e.g., whether population growth is focused on locations with high or low food access).

Recommendation 3: Measure Gini coefficient as an indicator of food access equity

In addition to looking at the total or average food access in the state, it is important to consider how food access varies from location to location. The average food access metric describe above is a combination of all locations in the state, so increases in food access for communities that already have good food access would result in an increased average, even if other communities are left behind. The Gini coefficient, defined in Section 3.3 and shown in Table 4.5, is a useful aggregate measure of the equitability of food access statewide. A perfectly equitable system (i.e., all census tracts have the same measured food access) has a Gini coefficient = 0, and a perfectly inequitable system (i.e., only one person experience any food access) has a Gini coefficient = 1. Therefore, the equity of food access by each mode can be compared and ranked. For example, Table 4.5 shows that food access is more equitable statewide by driving than by any of the other modes, which may indicate less consistent infrastructure and operations of transit services for people. Like the measure of food access itself, the Gini coefficient can be tracked over time to identify whether food access is becoming more equitable due to new transportation policies and investments.

5.1.3 Collaboration with Other Efforts to Measure Food Access

This research is not the first or only effort to measure food access in Massachusetts. Coordination and integration with other organizations that work on data collection and analysis of food access will extend the benefits of this information.

Recommendation 4: Coordinate with other efforts measure and analyze food access

Ongoing efforts by MAPC to measure and map food access include maintaining a database of food retailers and calculating the Food Access Index. MassDOT staff should work with MAPC to integrate the results of this analysis with those ongoing efforts. For example, the mode-specific access based on travel times, which is presented in this study, is important for representing the access that individuals experience as a consequence of the transportation network. Another parallel effort is a study of food access in the Pioneer Valley that has been funded by the Pioneer Valley Planning Commission (PVPC).

5.2 Moving Food to People

To the extent that food access in Massachusetts is a spatial problem that is affected by the transportation system, one strategy to improve food access is to move food to the people who need it. Although most policies to increase the availability of food fall outside MassDOT's purview, MassDOT can support other entities, such as municipal governments and regional planning agencies, by providing food access data as recommended above.

Recommendation 5: Coordinate with municipalities and regional planning agencies to support food access policies

There are several ways that MassDOT can support local and regional governments and agencies for policies that help move food closer to where people are. This coordination includes providing information about food access gaps and support to:

1. **Analyze candidate locations for new supermarkets in underserved communities:** One way to improve the measured food access—defined as the reachable square footage of supermarkets within a travel time constraint—is to identify underserved communities and incentivize the construct of more and larger supermarkets in those locations. Building supermarkets is not a conventional transportation policy, but it is something that can be incentivized for developers and food retailers through subsidies. Subsidies could be in the form of tax exemptions, zoning exemptions, or any incentive that can be given to encourage a food retailer to build a supermarket in a particular location. The source of funds for such a program may be local, but there are also grant programs that can provide support, such as the US Department of Agriculture's Healthy Food Financing Initiative (*46*), which is modeled after Fresh Food Financing Initiatives that were started in Pennsylvania and Maryland.

The best candidates for subsidized supermarkets would be locations where a business case can be made for a supermarket to be profitable, in which case the subsidy can tip the scale and/or reduce risk associated with opening a new store. This is most likely to be the case in urban food deserts, where there are many people in need of food access. In some cases, a supermarket can be part of a redevelopment or revitalization plan, because food access is a key amenity for attracting new residents to invest and reside in a particular neighborhood.

2. **Identify locations that may be candidates for pilot projects that involve delivering fresh/healthy foods to smaller stores:** Food deserts are characterized by a scarcity of full-service supermarkets that stock fresh produce and other healthy foods, yet often contain many convenience stores and gas stations that stock snacks and other processed foods. In some cases, the abundance of such stores constitutes a food swamp or an oversaturation of unhealthy food options in a particular area. Programs to deliver fresh produce to convenience stores in underserved communities can help to put healthy food options within closer reach of the people who need them. This is most beneficial for communities with significant numbers of households without access to a car and low food access by nondriving modes.

   The details of the program can vary. Example of such a program is the Healthy Convenience Store Initiative (HCSI) in Albany, New York and Healthy Corner in Washington, DC, which allow smaller stores to purchase wholesale fresh produce in small quantities so that can be sold profitably to customers. This reduces risk for business owners who cannot afford the losses if large quantities of produce spoil on store shelves.

3. **Identify locations that may be good candidates for establishing mobile or pop-up food pantries:** For communities with significant low-income populations, the affordability of food is a barrier to food access in addition to physically getting to a food retailer. Since the locations of brick-and-mortar food pantries are not always conveniently aligned with transit routes, it can be beneficial to bring free foods to the locations where there is need. Although the expense of opening permanent food pantry locations can be prohibitive, an alternative is to establish mobile or pop-up food pantries that can move around a community to distribute free foods on a regular schedule (e.g., a couple of days per month). These programs reduce the need for people to spend on transit to access low-cost healthy food options.

4. **Identify locations where the direct delivery of food to households should be prioritized:** One way to remove the burden of transportation from individuals entirely is to support delivery of food directly to households. This is particularly useful for serving people with limited mobility; e.g., people who are unable to drive or carry groceries. The most heavily subsidized programs could be targeted on delivering food to people free of charge (e.g., Meals on Wheels delivers food to vulnerable seniors for free).

   Technology advancements and the COVID-19 pandemic have prompted the development of several services that deliver groceries to a customer's doorstep, albeit for a fee. During the pandemic, the demand for grocery deliveries surged, and the convenience of home-delivered groceries has sustained its popularity; however, these delivery services are not available in all areas, particularly the rural ones. In addition, delivery fees can put these services out of reach for low-income households. Subsidizing grocery delivery services would improve food access for people who have limited income and mobility.

5.3 Moving People to Food

Naturally, an alternative to bringing food to people is to improve food access by making it easier for people to travel to food retailers. All of the recommendations in this section should be reflected in the metric for food access if the model for travel time by mode is complete enough to include all infrastructure and transit services.

Recommendation 6: Expand transit services in communities with low food access

One consistent take-away from the focus group discussions is that limitations in transit service translate directly into food access limitations. There are several ways that transit services can be expanded to enhance food access:

1. **Extend hours of transit operation:** A common challenge in less densely settled areas are limited transit service hours. Most fixed route transit services are designed and scheduled to carry commuters to and from work between standard peak periods. In suburban and rural communities, transit services are often limited or nonexistent during evenings and weekends. This limits the times which people reliant on transit can shop for groceries and may limit them to making purchases closer to home.

2. **Extend/redesign transit routes:** Although many transit agencies design transit routes so that there are stops at supermarkets, the structure of the route network is usually optimized for moving commuters to and from city centers. As a result, transit trips to get groceries may require transfers that significantly increase travel times. For example, PVTA service in Amherst has two routes that end at supermarkets (Route 33 connects UMass campus to a shopping center with Big Y and Stop and Shop; Route 36 connects the campus and town to Atkins Farm Country Market), but the network in Amherst is a hub and spoke centered around UMass and downtown, so travel to supermarkets from other neighborhoods requires transfer and circuitous path. Long travel times are problematic, especially in warm weather that can melt and spoil frozen or refrigerated items. Transit routes may also not reach the locations where populations in need are living, forcing people to walk long distances with groceries from transit stops to their homes. In communities with low food access by transit, routes should be designed with consideration of the locations of zero-vehicle households and food retailers.

3. **Expand microtransit services:** In many suburban and rural communities, the density of transit demand is too low to justify fixed route services. Demand response services carry passengers door-to-door from their homes to destinations within service

catchments around major roadway corridors rather than following fixed predetermined routes. Technologies now allow customers to communicate their desired trip origin and destinations and algorithms to route vehicles in real time, allowing demand response microtransit services to operate more cost-effectively than fixed route services in many rural communities (*47*). In communities with dispersed populations, microtransit also provides direct door-to-door service for customers, alleviating the risk of spoilage while transporting food home.

Recommendation 7: Include data on food access in the evaluation criteria for the MassDOT Community Transit Grant Program

One of the most direct ways that MassDOT can influence food access in the criteria used to allocate funds, for example for MassDOT's Community Transit Grant Program. By explicitly considering food access in the evaluation criteria for transit funding, MassDOT can support investments whose benefits might otherwise be overlooked. This is particularly important for projects in smaller and more rural transit agencies for which conventional transit performance measures, like ridership, may not be sufficient alone to justify an investment. Inclusion of food access data moves toward a more holistic project evaluation and selection process that addresses the needs of residents of Massachusetts.

Recommendation 8: Improve integration/coordination between transit agencies particularly in areas that have been found to have low food access

A consequence of transit services being operated by fifteen different RTAs and the MBTA in Massachusetts is that jurisdictional boundaries do not necessarily align with the public's travel needs. Transit agencies focus on serving trips that start and end within their service area. This can work well for people who live, work, and shop within a small number of proximate municipalities, however, there are many suburban and rural communities that are located at the edges of RTA service areas. This is especially problematic since the nearest or most appealing food retailers may be in another RTA's service area. Without close coordination between RTAs and the state to align routes and schedules, it can be difficult or impossible to conveniently travel by transit from one region to another in a timely manner.

Recommendation 9: Improve pedestrian and bicycle connectivity in the vicinity of grocery stores and other food retailers, particularly in areas found to have low food access and low-comfort pedestrian and bicyclist networks

In many communities the lack of infrastructure for pedestrians and bicycles poses a barrier to mobility. Outside of urban neighborhoods, food retailers are typically in spaces designed to be used by cars. Even when straight-line distances are short, a lack of sidewalks, crosswalks, and paths can make a trip circuitous, uncomfortable, or dangerous by walking and bicycling. Although connections to the locations of food retailers themselves are important, facilities for pedestrians and cyclists providing access to transit services are also important throughout a community.

It can be challenging to measure the effect of improved pedestrian and bicycle infrastructure on food access. The GIS tool used for the analysis in this report, Conveyal, accounts for network travel times for walking and cycling (as described in Section 3.2.2). New links in the network, such as a pedestrian bridge across a highway or multiuse trail, would be reflected in improved accessibility using this tool. Changes to existing infrastructure, such as improved signage at crosswalks, installation of protected bicycle lanes, or repair of damaged sidewalks, would not change the measured food access using this method. However, improvements to pedestrian and bicycle infrastructure, including amenities at transit stops, would make it easier and safer for people to walk and bike for all trip purposes, including accessing food regardless of whether these improvements are measurable using this specific methodology.

The recommendations described in this section would be appropriate for locations across the state that are identified as having low food access by transit, as illustrated in Figure 4.8 (measured food access) and Figure 4.20 (residual of modeled food access). For example, the town of Deerfield experiences a lack of food access across all modes by the metrics used.

- Expansion of transit service in Deerfield already includes provision of the Access microtransit service. Additional consideration for how existing fixed route services connect food-insecure households with food retailers and food pantries could also be used to adjust routes or hours of operation.

- Residents of Deerfield, Massachusetts, are served by Franklin RTA but the nearby shopping centers in Hadley, Massachusetts, are served by Pioneer Valley Transit Authority. As reported in the focus groups (Section 4.4.2), traveling from one community to the other, while not impossible, is time-consuming and requires multiple transfers.

- As a rural community, few residents of Deerfield can meet their food access needs only by walking, but there is always a walking component to a trip made by transit. Improving pedestrian and bicycle facilities between locations where people live and transit stops improves their ability to use transit as a means to access food. For persons with disabilities, adequate accessible infrastructure (e.g., sidewalks, crosswalks with curb cuts, paved space and benches at transit stops) can be the determining factor for whether transit can be used at all.

5.4 Changes in Policies or Regulations

Some improvements to food access could be achieved by changing rules and regulations by various levels from regional transit up to federal agencies. These changes would not affect the measured food access using the spatial analysis as described in this study but would improve the ability for people to access food.

Recommendation 10: Increase carry-on limit for transit

Transit services typically limit the number of bags or items that a passenger can bring onboard to the amount that can carried when they step onto the bus—typically understood to be a two-bag limit, one in each hand. For example, the PVTA's stated policy is that "Items brought on board such as backpacks, bags, suitcases, etc. must be stored in the passengers lap or underneath the seat. Items must be kept out of the aisle and these items are not allowed to be stored on other seats on the bus" (*48*). The purpose of these limits is to maintain efficient boarding of buses and other vehicles; and to ensure that passengers do not bring so many belongings that seating space for others is limited. On high ridership transit routes, this is important for scheduled adherence and ensuring sufficient seating capacity for the passengers. However, this limit is a serious constraint for people using transit to carry home groceries. Although policies to limit carry-on bags may be important during peak hours, transit agencies should consider relaxing such restrictions during periods of lower demand when the consequences of someone bringing aboard extra groceries would be negligible. This is most likely to be the case during off-peak hours that include evenings, weekends, and perhaps midday hours.

Recommendation 11: Allow vehicles to be used flexibly for passenger and food transportation

Another challenge for addressing food access is acquiring vehicles to either move people or food. Especially in smaller, rural areas, it is important to be flexible with how resources are used, because it may be more efficient to meet different needs at different times using the same vehicles. Typically, a van that used to provide transportation for passengers during weekdays may sit unused on a weekend when there is a need for a vehicle to transport food to a mobile food bank. An exception to allow use of vehicles for food delivery is called "incidental use." This was allowed during the COVID-19 pandemic as part of Emergency Relief using FTA 5307/5311 formula funds until January 20, 2022, subject to FTA approval. Since January 2022, only funds from the Coronavirus Aid, Relief, and Economic Security (CARES) Act, Coronavirus Response and Relief Supplemental Appropriations Act, 2021 (CRRSAA), and American Rescue Plan (ARP) Act are eligible for incidental use (*49*). The criteria for approval require that incidental use does not impact the provision of passenger service. It is important that current policies regarding incidental use are communicated clearly to transit agencies. We also recommend that any FTA funds be eligible for an exception, so that agencies have the flexibility to utilize the resources at hand.

6 Conclusions

This study explores inequities in food access across Massachusetts. The methods include spatial analysis, machine learning, and focus groups to systematically gather data, analyze patterns, and identify policies and investments to improve food access across the state. This work makes contributions in the methods used to measure the spatial aspects of food access and the analytic techniques used to quantify equity and identify food access gaps. This study also makes the practical contribution of recommending policies and investments that can be implemented to improve food access in communities across Massachusetts. Finally, we discuss possible caveats and limitations of this study and directions for additional research.

6.1 Methodological Contributions

The combination of spatial analysis and modeling provides useful insights on food access in Massachusetts and identifies communities that are underserved in terms of food access. Rather than counting the number of stores within a distance buffer, which is a typical measure in the literature, we propose using the total square footage of supermarkets that can be reached within a travel time constraint as the measure of food access. The floor area of supermarkets serves as a proxy for the breadth of choice available at a supermarket, and the comparison of modes reveals the difference in food access for people who travel by means other than their own car.

The results of the spatial analysis show that food access varies greatly across the state of Massachusetts. Although locations with higher food access are concentrated in urban areas that also tend to have higher poverty rate and minority populations, the picture differs significantly depending on the mode of transportation considered. When considering access to food by walking, the data show that communities with the lowest food access are associated with elevated poverty rate and lower vehicle ownership, exactly the characteristics of people more likely to rely on walking. Food access by driving is associated with more a wider range of socioeconomic characteristics, including communities that have higher household income. The inequities in food access for those who do not have access to a car are also highlighted by the Lorenz curve analysis, which shows that food access is most equitable across the state when considering access by driving. Altogether, these results show that there is a need to consider the relationship between transportation mode and food access, and that vulnerable socioeconomic groups are more likely to experience access to healthy food options. The maps reveal that urban areas such as Boston, Lowell, and Springfield have greater food access and are characterized by higher percentages of minority populations and higher proportions of households experiencing poverty compared to the statewide trends.

The GBM identifies the most important factors, i.e., population density and vehicle ownership, which align with spatial trends showing higher food access in high density areas and high vehicle ownership in low food access suburban areas. The machine learning models, estimated using GBM, show that population density is the most important variable for all the transportation modes, and car ownership is an important determinant of food access. The poverty rate and the percentage of population identifying as a racial or ethnic minority are also relevant determinants of food access. The analysis of model residuals shows that even when accounting for socioeconomic characteristics of communities, gaps in food access exist across Massachusetts.

Finally, plotting of the measured food access allow us to determine the areas characterized as underserved in terms of access to food based on statewide trends, therefore, revealing potential inequities. The maps showing the ratio of bounded residuals illustrate that greater food access across the state is achieved by car while the driving model has the lowest CV, indicating that the model makes the most reliable predictions for food access by car in part because cars provide a greater magnitude of food access and also because it is relatively more equitable than other modes.

Ultimately, the value of food access metrics, analysis of Lorenz curves, and model residuals is their reproducibility and consistency in tracking food access across spatially and temporally. As policies are enacted to improve transportation or develop more food retail locations, the proposed methods provide an objective and quantitative way of tracking progress toward the societal goals of increasing food access and equity. In this way changes in food access within a specific community and in the equity of food access statewide can be tracked as measures of the impact of investments.

6.2 Recommendations

One of the most important reasons for using quantitative techniques to measure food access is that it allows planners and decision makers to take action to improve access to food. A lack of food access, as defined in this study, represents a fundamental mismatch between the locations where people live and the locations where food is sold. Based on the data analysis and results of the focus groups, twelve recommendations are made in four general categories:

1. Statewide metrics of food access (Section 5.1),
2. Moving food to people (Section 5.2),
3. Moving people to food (Section 5.3), and
4. Changes in policies or regulations (Section 5.4).

It is also important to recognize the food access is a multifaceted problem, which is highly dependent on local context. As such, not all recommendations are necessarily appropriate or applicable to every community. Many of the recommendations are most appropriate for improving food access for people that do not have access to a car and for people with limited incomes. These are environmental justice populations, which are vulnerable to food insecurity, and for whom changes to improve food access will have the greatest impact.

6.3 Limitations

Some limitations of this study are associated with the types of data available for comprehensive statewide analysis and the ways that food access are defined. A key caveat of this research is the focus is on food access from a spatial/transportation perspective alone. Defining food access by the square footage of supermarkets that can be reached within a travel time constraint illustrates the availability of food rather than its affordability. Food insecurity is more complex than just physical access to places that sell or provide food, and it is entirely possible for a household to experience food insecurity in proximity to a retailer that sells food that is either too expensive or culturally inappropriate. Even if low-income populations live in centers where food services are available it does not necessarily mean that they provide affordable choices. Although square footage of supermarkets is intended to be a proxy for food choice, the price of food is not part of the statewide data set used. Consequently, alternative metrics should be used to explore the issue that can capture affordability, e.g., accounting for product prices.

Another limitation of the study is related to spatial granularity of the analysis and the types of transportation data considered in the spatial analysis. Census tracts are a convenient spatial unit for analysis because demographic data is readily available for the same zones. However, census tracts vary greatly in size across different parts of the state, representing parts of neighborhoods in dense cities and multiple towns in rural areas. For census tracts that are larger in area, the location of the centroid may not coincide with the locations of population centers and therefore not be particularly representative of where people live. This could be addressed by identifying locations of population centers or utilizing a finer spatial unit in less densely populated areas. In terms of equity, there is more concern and more need for interventions to address food access gaps for populations that experience food insecurity. The specific locations where REJ+ populations are living within a town do not necessarily coincide with the census tract centroid and are not accounted for in this study.

A final limitation is that the network analysis is based on the infrastructure and transit services that are coded into the GIS layers used by Conveyal. The data is effective for the street network used by cars, and it provides reasonable travel times for bicycles and pedestrians on this network. Fixed route transit services are also well-represented in the model. The challenge is that newer microtransit services, which do not operate on a predefined route or schedule, are not currently reflected in Conveyal's transit travel time estimates. It would also be important to determine the extent to which pedestrian facilities, such as sidewalks, crosswalks, and crossing signals are considered in the walking travel times. Ultimately, the tool does provide a consistent and reproducible way to analyze food access across all parts of Massachusetts, but it will also be important to consider these details if investments to improve infrastructure for walking, bicycling, and transit are to be reflected in the metrics of food access.

6.4 Future Research

There are a number of directions for future research on food access, specifically, and access as a determinant of social health, more generally. In the realm of food access, it is clear from this study that there are large disparities in food access across Massachusetts, but there are certain populations that are particularly vulnerable to food insecurity. These include the environmental justice populations, which includes people living in poverty, minority populations, and households without access to a car. From the focus group discussions, it is apparent that there are also significant problems with food insecurity among the elderly and people with disabilities. Additional research could look more specifically at where spatial gaps in food access align with concentrations of these vulnerable populations, because these are places most in need of policies and investments which improve food access. An important element of this is to extend the analysis of transit access to include microtransit services.

More generally, access is an important consideration for other determinants of public health. MassDOT has already developed a jobs access dashboard to use data to analyze access to jobs across the state. Other important amenities to consider are healthcare, education, and recreation facilities. Metrics for each of these would need to be carefully defined based on the characteristics of the opportunities and their effect on public health (e.g., healthcare access may include hospitals, urgent care centers, primary care doctors, or other specialists). The methodological basis of the spatial analysis proposed in this study could serve as a foundation for developing those metrics. For example, defining areas that can be reached within a travel time budget by different modes can be component of defining a healthcare accessibility measure that would count the number(s) of relevant opportunities that can be reached.

Drawing the connections between accessibility and actual health outcomes is even more complicated. What is recognized is that disparities in accessibility across Massachusetts have an impact on the people living in different communities. Improving quality of life and public health across the state requires first understanding the life experiences and challenges of the residents of Massachusetts. Only with this understanding and tools to measure progress can investments be made to equitably improve accessibility statewide.

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Appendix A: Summary of Food Access Metrics

Table A.7 Summary of food access metrics

Proximity Metrics	**Proximity metrics have simple interpretations: how close is the nearest food? These metrics have relatively simple data requirements.**	**By looking only at the nearest store, these measures do not account for the diversity of choices available to people.**	**References**
Distance (Euclidean) to nearest store	• Simple measure requires only store location data	• Euclidean (straight-line) distance does not account for network structure of speeds	(*16,25,26,31*)
Distance (network) to nearest store	• Represents the actual distance that must be traveled based on the transportation network	• Requires data on the spatial representation of the network and GIS analytics	(*27,37,50*)
Travel time to the nearest store	• Represents that time that people must spend traveling to reach a store, which accounts for speeds on the network • Reflects the time constraints that typically limit how far people can travel	• Requires data on speeds across the network for all of the modes considered; travel times may vary by time of day • Requires knowledge or assumptions of the transportation modes that people use	(*22,51–53*)
Average distance to store for an area	• Provides a measure of food access that aggregates the experiences of household across an area, such as a census block or census tract	• Analysis can no longer be based only on individual points (e.g., centroid of a census tract), because the distribution of household locations must be known	(*11*)
Density Metrics	Density metrics represent how many food stores can be reached within an area, often defined by a distance or travel time constraint. These metrics can be interpreted intuitively, and greater density is typically an indication of greater variety of choice.	The metrics require a geographic area to be defined, often by a distance or travel time threshold. This makes these metrics susceptible to edge effects beyond which stores are not counted.	—
Number of stores within a census tract	• Simple GIS analysis reveals the density of stores within a defined geographic area	• Census tracts can vary greatly in size from urban to rural areas. In large census tracts, there is no way to know if multiple stores are distributed uniformly across the area of clustered in one location.	(*34,54*)
Number of stores within a distance threshold	• Provides a consistent basis for comparing food access across different communities • Indicates the variety of choice that is accessible from a location	• Distance (whether Euclidean of network) does not account for the speed of travel • No information about the types of stores are accounted for to indicate if they represent a variety of prices, selection, open hours, etc. • It can be difficult to identify the appropriate distance threshold	(*16,26,28,51*)
Number of stores within a travel time threshold	• Provides a consistent basis for comparing food access, which also accounts for the speeds on the network • Indicates the variety of choice that is accessible from a location • Reflects the time constraints that typically limit how far people can travel	• Requires data on speeds across the network for all of the modes considered; travel times may vary by time of day • No information about the types of stores are accounted for • It can be difficult to identify the appropriate travel time threshold	(*22,52,53*)

Price/Cost Metrics	The price of food and the monetary cost of travel affect the affordability of food. Metrics that include the price or cost provide insight about the equity of food access across income levels.	Although household income data is generally available with the census, data on the prices of food in stores are time-consuming to collect and keep updated.	—
Difference between distance to nearest low-cost store and nearest store	• Represents inequity in food access based on the affordability of food	• Requires data on food prices to classify which stores are low-cost • The difference in distance alone does not indicate the magnitude of distance to the closest store; both may be very far	(*55*)
Travel cost to the nearest store	• Includes monetary costs of travel in addition travel time to reflect the affordability of travel to food	• Requires data on costs of travel by modes considered, some of which may vary between individuals	(*32*)
Number of stores within a travel cost threshold	• Includes monetary costs of travel in addition travel time to reflect the affordability of travel to food	• Requires data on costs of travel by modes considered, some of which may vary between individuals	(*23,56*)
Store Visit Metrics	Metrics of shopper behaviors show how people are currently meeting their food access needs. The frequency of visits and which stores are visited provides insights about what level of food access people desire.	Tracking shopping behavior requires data that must be collected by surveys, which is costly and time-consuming to collect.	—
Percent of people shopping at the nearest store	• Shows how well accessible food stores match the needs of nearby communities. A low percentage indicates that people prefer to travel further for food either because the closest store is too expensive, does not offer the quality of selection desired, or is not culturally appropriate	• This analysis requires the data for a proximity analysis in addition to data on individual behaviors that requires surveys	(*24*)
Frequency of grocery store visits per month	• Shows how often people are traveling to buy groceries. A high frequency may mean that stores are convenient and therefore easy to access often, or if may be an indication of a persons limited ability to carry large quantities of food in a single trip.	• A survey is needed to collect information individuals about their food shopping habits over period of time.	(*24*)
Number of stores visited per month	• The number of different stores visited provides an indication of how many different stores are needed to satisfy someone's food preferences.	• A survey is needed to collect information individuals about their food shopping habits over period of time.	(*24*)

Indices	Indices are a way to turn complex or multifaceted metrics into a single numerical score. This can facilitate interpretation of food access data by resolving some of the shortcomings of metrics listed above or combining elements like proximity and income.	By nature of the way they are calculated and constructed, the numerical value of indices usually does not physical units.	—
Ratio of food stores to population within a geographic area	• Shows the relative density of stores by controlling for the population	• The ratio of stores to population may not be a very important indicator of food access for rural areas, because even people living in low density areas need some minimum access to food	(*57–62*)
Grocery square footage per household	• Shows the provision of store space by controlling for the population • Using square footage provides an indication of the variety of foods that are likely to be available as opposed to just the number of stores	• Requires data on the size of grocery stores • The same square footage per household between an urban and rural area may translate to large supermarkets and small convenience stores, respectively. These do not provide the same food access.	(*63*)
Gravity or distance-decay measures	• Measures of food access that give stores diminishing weight with increased distance (analogous to the reducing force of gravity with distance) eliminates the edge effects with other density metrics • The parameters of the measure can be calibrated to represent the trade-off between proximity and variety in considering food access from a location	• These measures are really models that must be calibrated which makes them more difficulty to use • The meaning of the resulting metric is also more difficult to communicate	(*21,58,63–68*)
Food Access Index	• This index weights stores by type from 1 (small convenience stores) to 5 (large supermarket) so that the variety of accessible stores is accounted for	• Requires that food retailer data is detailed enough to categorize stores by type • Network distance thresholds are used, which do not account for travel speed or cost	(*29*)
New food prioritization area	• A combined measure of income (<$35,000 per household per year) and density based on network distance to identify food deserts	• Distance threshold does not account for speed or cost of travel	(*20*)
Market interaction potential	• Measure of the relationship between food demand and supply seeks to identify where the market is aligned so that the people who want to buy food are able to do so	• This requires data on food sales at individual stores	(*33,39*)
Healthy/unhealthy food availability index	• A detailed look at the ratio of healthy food to unhealthy food on the shelves of accessible stores provides and indication of the prominence of healthy accessible foods	• Detailed data on the selection of foods and prices within stores is costly and time-consuming to collect	(*30*)

Appendix B: Presentation Slides for Focus Groups

B.1 Amherst Focus Group

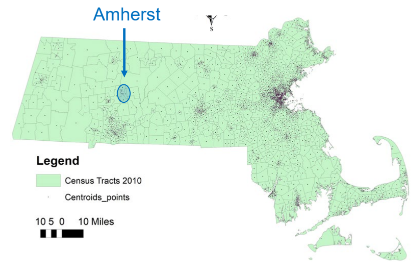
Data for Massachusetts

Demographics

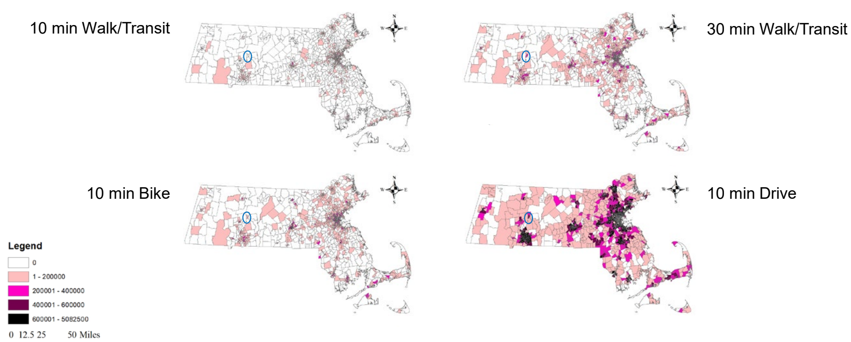
- US Census (1472 census tracts in MA): population, income, race
- MAPC Demographic Data – poverty rate, household size, vehicle ownership

Food

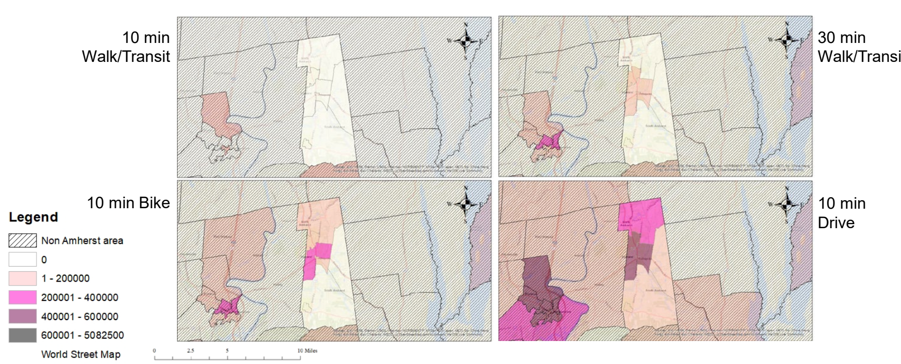
- MAPC Food Retailers in Massachusetts: store location and type



Accessible Square Footage of Supermarkets by Mode

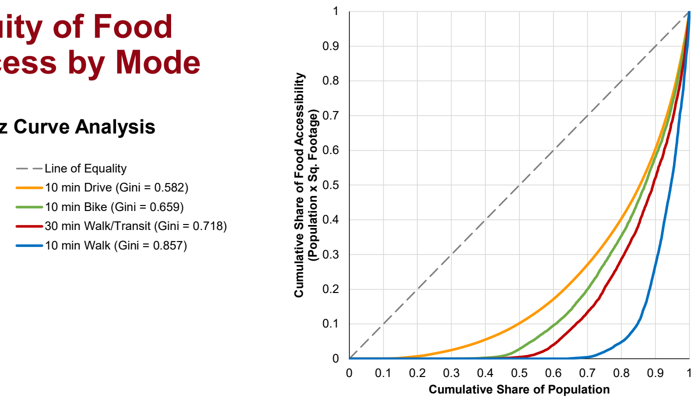


Amherst, MA Sq Ft. of Reachable Supermarkets

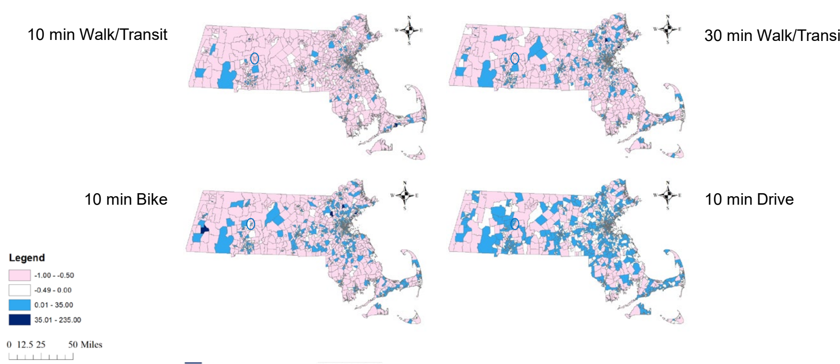


Equity of Food Access by Mode

Lorenz Curve Analysis



Model of Relative Food Access



Amherst, MA Relative Food Accessibility

B.2 Deerfield Focus Group

Measuring Accessibility to Improve Public Health

MassDOT funded study of the connection between transportation and food access

- Identify areas lacking access to food
- Develop models to understand the connection between socioeconomic variables and access to food
- Engage stakeholders to develop recommendations to improve food access

Source: https://www.goodfoodia.org/food-security-and-access

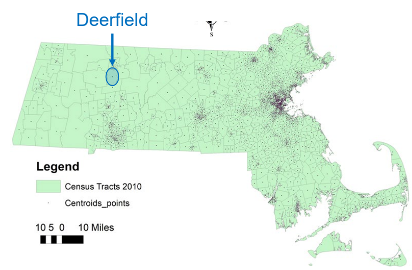
Data for Massachusetts

Demographics

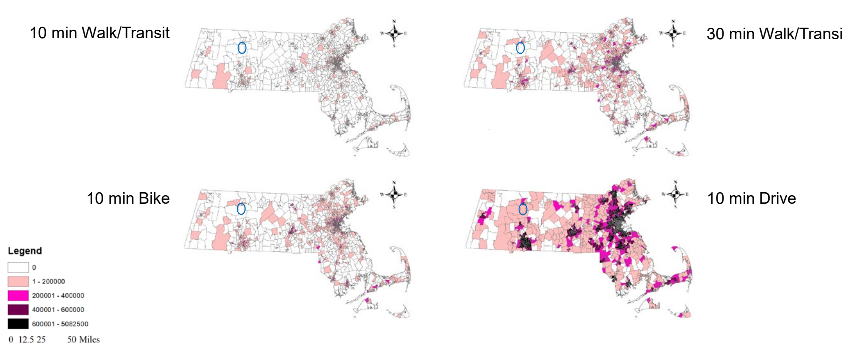
- US Census (1472 census tracts in MA): population, income, race
- MAPC Demographic Data – poverty rate, household size, vehicle ownership

Food

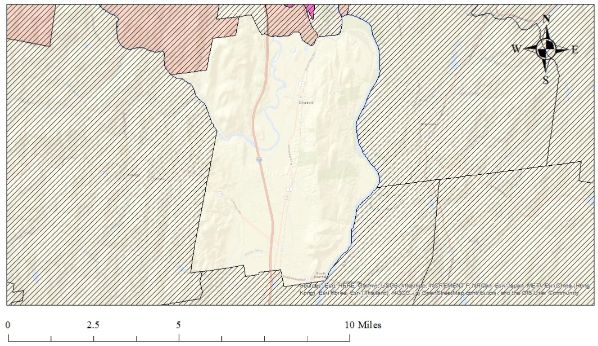
- MAPC Food Retailers in Massachusetts: store location and type



Accessible Square Footage of Supermarkets by Mode



Deerfield, MA Sq Ft. of Supermarkets within 30 min Walk/Transit



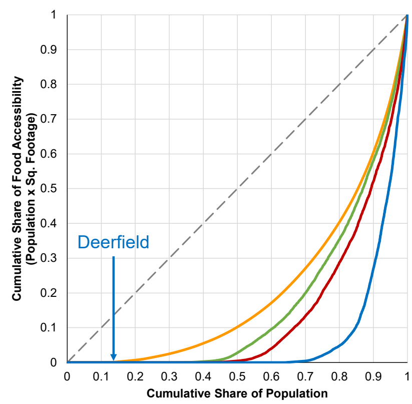
Legend

- Non Deerfield area
- 0
- 1 - 200000
- 200001 - 400000
- 400001 - 600000
- 600001 - 5082500
- World Street Map

Equity of Food Access by Mode

Lorenz Curve Analysis

- Line of Equality
- 10 min Drive (Gini = 0.582)
- 10 min Bike (Gini = 0.659)
- 30 min Walk/Transit (Gini = 0.718)
- 10 min Walk (Gini = 0.857)



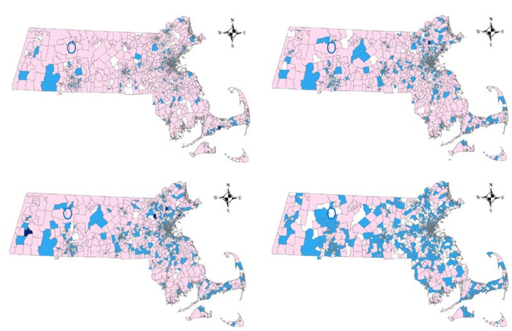
Model of Relative Food Access

10 min Walk/Transit

30 min Walk/Transit

10 min Bike

10 min Drive

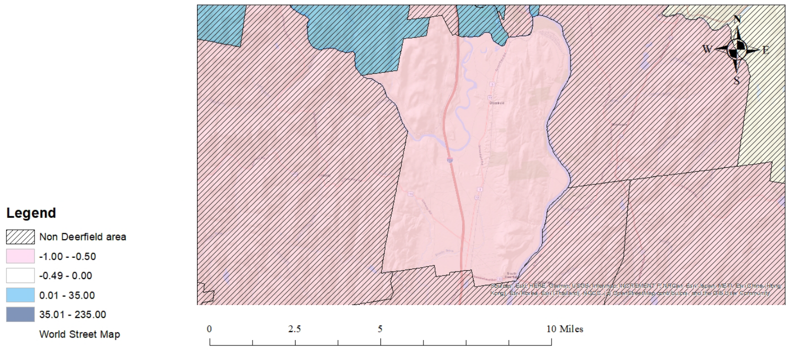


Legend

- -1.00 - -0.50
- -0.49 - 0.00
- 0.01 - 35.00
- 35.01 - 235.00

0 12.5 25 50 Miles

Deerfield, MA Relative Food Accessibility 30 min Walk/Transit



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DISCUSSION

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