I, Jingwei Ning, hereby submit this original work as part of the requirements for the degree of Master of Arts in Geography.

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Improving the USDA’s Definition of Food Deserts via a Spatial Interaction Approach
A Case Study of Hamilton County, Ohio

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Improving the USDA’s Definition of Food Deserts via a Spatial Interaction Approach
A Case Study of Hamilton County, Ohio

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Abstract

Adequate consumption of healthy and high-quality foods is essential for the prevention and management of public health conditions, such as obesity, diabetes, cardiovascular disease, and some cancers. Access to healthy foods is a critical public-health concern, and, consequently, there is an increasing interest in mapping the food environment and identifying food deserts, or those areas where people have significantly limited access to retail sources of healthy, nutritious and affordable food because of spatial distance and/or socioeconomic deprivation. In May 2011, the U.S. Department of Agriculture (USDA) launched a food desert locator that pinpoints the location of food deserts across the country by census tract units. A clear definition of “food deserts”, together with the criteria and methods applied for the identification were announced, based on the national-level analysis conducted by the Economic Research Service (ERS-USDA). A census tract that qualifies as both a “low-income community” and as a “low-access community” is defined as a food desert. However, the arbitrary criteria for identifying the “low-access community” have been criticized for their inability to account for both the detailed spatial variations of population demand and food supply within the aggregated geographic units (census tracts), and the interactions between them. To address these criticism and evaluate the integrity of the USDA’s definition of food deserts, this study applies a GIS-based two-step floating catchment area (2SFCA) method to measure spatial accessibility to food sources, employing a higher resolution grid-based population data, and identifying what comprises a “low-access community” based on the weighted mean of accessibility scores at the census tract level. Combining this with the same criteria for the “low-income community”, the modified spatial interaction based approach is utilized to assess the local food environment in Hamilton County,
Ohio. Differences between the re-identified food-desert census tracts and the official “food deserts” as defined by the USDA is demonstrated, the examination of which argues for improvements in identification practices currently in use by the USDA. The proposed method in this study has the potential to help policy makers or community planners to more explicitly identify and delineate food deserts, thus enabling greater accuracy and identification of the real problems in local food environments.

Key Words: Food Deserts, Food Access, Spatial Accessibility, GIS
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<td>Two-step floating catchment area</td>
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<td>ERS</td>
<td>Economic Research Service of the USDA</td>
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<tr>
<td>FCA</td>
<td>Floating catchment area</td>
</tr>
<tr>
<td>NAICS</td>
<td>North American Industry Classification System</td>
</tr>
<tr>
<td>SNAP</td>
<td>Supplemental Nutrition Assistance Program</td>
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Chapter I: Introduction

The continuing transformation of technological, demographic, social and spatial contexts of American health care and food environments implies that there are frequent shifts in our emphasis on various dimensions of access to health-related resources, such as good-quality food sources, health care providers and urban green spaces. Food, as one of the basic needs for human existence, provides sustenance, economic stimulus and a sense of community. Access to healthy food providers (grocery stores and restaurants, for example) is being recognized as an important facilitator of overall population health since a good-quality food intake in daily life is the first line of defense for the population and the most critical part influencing human body conditions.

For many Americans, purchasing fresh fruits and vegetables means a routine stop at the local supermarket. However, for those Americans who live miles from the nearest food retail supplier, eating healthfully is challenging because nutritious and affordable food is not available in close or accessible proximity to them or to their neighborhoods. Data from National Health and Nutrition Examination Survey conducted by the Centers for Disease Control (CDC) (2012) confirm that there is an obesity crisis in the United States: these data show that there has been a dramatic increase in obesity rates in the U.S. during the past five decades, from 13.4 percent in 1960-1962 to 35.7 percent in 2009-2010. In addition, none of the 50 states had an obesity rates lower than 20 percent in 2010. These increases in obesity rates exacerbate possibilities for development of other chronic diseases, and are linked to the increased consumption of energy-dense foods that are high in fat, salt and sugar but low in vitamins, minerals and other micronutrients (WHO 2011). The growing obesity epidemic has been blamed on being caused by several factors, and evidence has been found that links presence or absence of supermarkets in
one’s neighborhood with obesity rates, with a presence of supermarket associated with lower prevalence of obesity, while proximity to convenience stores and fast food restaurants significantly increases the risk of obesity (Currie et al. 2010; Morland et al. 2006). Another issue of concern is that compromised access to supermarkets or full service-grocery stores coupled with easier access to fast food is also linked to poor diets and diet-related diseases (USDA 2009).

Motivated by concerns about rising obesity rates and the assumption that differences in food access affect dietary intake and ultimately subject a population to greater risks of overweight and other obesity-related diseases, numerous studies have been conducted to study the food environment in a variety of social science disciplines over the last two decades. There is a growing interest in the environmental context as a catalyst related to food behavior, and this food environment includes both the physical and social components.

The U.S. grocery retail sector has undergone significant restructuring in recent years. As a consequence of greater corporatization, independent grocery stores run by a sole proprietor have been rapidly disappearing from the landscape, and larger chains have been merging with and buying out smaller chains, effectively demonstrating that notion that most of the large retailers, driven by business concerns rather than concerns for populations in need, have been increasingly moving to more affluent suburbs (Clarke et al. 2002). These grocery retailers tend to offer a larger variety of healthy and inexpensive food, and thus have great influence on the dietary habits of residents who live in the neighborhoods surrounding them. Previous research has discovered that, at a national scale, there are fewer and smaller grocery stores in low-income zip code areas (Cotterill and Franklin 1995; Donohue 1997). Meanwhile, the rapid spread of fast-food chains in the inner cities propels greater overexposure of more and more socially disadvantaged individuals to unhealthy food choices, thus subjecting this segment of population
to suffer from higher risks of obesity and other devastating health issues. The combined effects of the high-end suburbanization of grocery stores offering healthy foods and the greater proliferation of fast-food and convenience stores as sole food resources, have left a profound impact on the adverse health outcomes of affected populations and has raised many concerns regarding the problem of food deserts.

In physical geography, a desert landscape is characterized by certain aspects of topography, soil and precipitation pattern, and cognitively evokes images of vast, arid spaces filled with sand and dust, and inhabited by unique flora and fauna adaptable to sparse amounts of precipitation and subjected to living in a biome without adequate or sufficient water resources. Food deserts are thus likened to physical desert regions in that searching for and acquiring nutritious foods is not easily accomplished in either environment. In urban geographic studies, the literature on geographies of food names areas with a lack of access to adequate food as food deserts (Hallett and McDermott 2011). The concept of the food desert originated in western Scotland in the early 1990s (Beaumont et al. 1995; Dept. of Health 1996). In 1996, the term *food desert* is used for the first time in a report issued by a United Kingdom government commission, where the term is defined as “areas of relative exclusion where people experience physical and economic barriers to accessing healthy food” (Cummins and Macintyre 2002a; Reisig and Hobbiss 2000). In recent years, this term has become popular and is used to describe a number of situations of limited food environments in studies of different social science disciplines. It has been summarized that a neighborhood may or may not have a food desert depending upon what one’s definition is, and in fact the term is more conceptual and qualitative than categorical and no particular consensus classification has been accepted (Eckert and Shetty 2011). For example, one study defines food deserts as “urban areas with 10 or fewer stores and no stores with more
than 20 employees” (Hendrickson et al. 2006: 372). In another study, food deserts are described as “poor urban areas, where residents cannot buy affordable, healthy food” (Cummins and Macintyre 2002a: 436). In the 2008 Farm Bill, food desert is defined as “an area in the United States with limited access to affordable and nutritious food, particular such an area composed of predominately lower-income neighborhoods and communities” (Food, Conservation, and Energy Act of 2008: 2039). This act further commissioned an ERS (Economic Research Service) report from the USDA that assessed the extent of the problem of limited access to food stores in the U.S., and addressed the causes and effects of food deserts (USDA 2009). One conclusion from the report was that 2.3 million (2.2%) of all U.S. households live more than a mile from a supermarket and do not have access to a vehicle. Sparks et al. (2009) then summarized those various definitions into one general idea: food deserts are urban areas in which residents lack spatial access to fresh fruits and vegetables, to foods from all the major food groups required for an adequate diet, and to food competitively priced. Adequate retail provision, including variety, price, availability, as well as the mobility issues, have also played critical roles in characterizing food deserts. Additionally, Raja et al.(2008) further stated that a certain area with an absence of supermarkets alone cannot be defined as a food desert, considering there are smaller retail outlets that do exist, or that financial and transportation facilities make it easy and feasible for the residents to do grocery shopping outside the neighborhood. Certain food deserts do include food retail outlets within urban areas; however stores that can provide a wide range of healthy food and grocery items at relatively low prices are lacking. In February 2010, the Obama Administration proposed a $400 million Healthy Food Financing Initiative, part of which promotes healthy food retailers to move to underserved urban and rural communities (USDHHS 2010).
More recently, as part of First Lady Michelle Obama’s *Let’s Move* initiative, the USDA has also launched a food desert locator that indicates areas in which there is low access to supermarkets or other sources of fresh produce (USDA 2011). Along with the interactive mapping tool that enables users to track the location of food-desert census tracts and to view the related demographic information of those tracts, a more specific definition of food desert devised by the Health Food Financing Initiative (HFFI) is highlighted, where a *food desert* is defined as “a *low-income census tract* where a substantial number or share of residents has *low access* to a supermarket or large grocery store.” (USDA 2011, emphasis in original) Criteria for the two key terms mentioned in the definition are specifically described as follows: (1) a “low-income community” refers to a census tract with a poverty rate (i.e. the percentage of population living below the poverty line) of at least 20 percent or a median family income no more than 80 percent of the greater statewide/metropolitan area median family income; (2) a “low-access community” is defined as a census tract with at least 500 people or 33 percent of its population living more than one mile away from a supermarket or a large grocery store in urban areas, or more than ten miles in rural areas (USDA 2011).

Using these income and access criteria, 10 percent of the nearly 65,000 census tracts in the United States are identified as food deserts. And these food-desert tracts are home to nearly 13.5 million people with low access to sources of healthy food (USDA 2011). While these designation criteria have made important strides in identifying and documenting the presence of food deserts at the census tract level based on a standard line, it has been limited in some critical ways. First, the cardinal value of 500 people and the population percentage of 33 are fixed numbers and are applied to all census tracts across the United States, irrespective of actual census tract population or size. This type of “one-size-fits-all” definition may easily lead to
overestimation or underestimation of the food desert problem in certain areas, and ultimately these population constraints cannot accurately reveal the disparities in food access at a more localized scale. Second, geographic proximity is the only component employed in the definition of accessibility – there is no consideration given to the interactions between supply and demand (food providers and population) across census tract boundaries: instead the accessibility definition focuses only on the demand aspects, situating the food providers proximate to a 1-mile buffer of the corresponding population. Furthermore, the definition of “low-access census tracts” assumes that the remainder of the population located within 1-mile service areas are well served by food stores, assuming evenness in accessibility from all points within that buffer, with no consideration given to the ease or extent of that accessibility. These limitations found in the criteria have raised questions regarding the reliability of a census tract as being “officially” designated as a food-desert tract. For instance, New York City officials have questioned the validity of the definitions used to generate the food desert data, citing evidence that only 26,000 New Yorkers are identified as living in a food desert according to USDA criteria, while their own estimation places the number of population affected to be as high as 3 million (Eversley 2011).

Even though researchers have conducted prior studies using different methods to measure accessibility in order to investigate if certain study areas have food deserts according to their own accessibility standards, no published research has ever compared results of these endeavors to the “official” food-desert census tracts as designated by the USDA at a more localized scale. This thesis seeks to fill the gap and proposes to conduct an analysis of food deserts in Hamilton County, Ohio. According to the USDA’s food desert locator, Hamilton County has 26 census tracts that have been identified as food-desert census tracts, with a total combined population of
75,000 (Figure 1.1). The objective of this thesis is to investigate if there is any methodological limitation in the USDA approach for identifying food deserts and to evaluate and improve the USDA’s definition, employing the two-step floating catchment area (2SFCA) method, a GIS-based spatial interaction method that measures the spatial accessibility and re-defines the criteria for what constitutes a “low-access community”. Adhering to the same income criteria as the USDA, a new group of food-desert census tracts are identified. The re-identified food deserts are then compared to the USDA’s results to see if tracts are underestimated or overestimated.

**Figure 1.1** Food desert in Hamilton County, Ohio identified by the USDA’s Food Desert Locator.

A limitation is that USDA does not disclose their proprietary data source of supermarkets and large grocery stores; therefore this study relies on another database to obtain the food store data. A preliminary examination of the new dataset is conducted to ensure the data consistency.
and confirm the validity of using a different data set to replace the USDA’s food store data. In this study, supermarkets and large grocery store data in Hamilton County are obtained from Reference USA, and are then filtered based on the North American Industry Classification System (NAICS) codes. Population and income data at the census tract level for the year 2000 are obtained from U.S. Census Bureau, enabling consistency to be kept with USDA’s data source.

The analysis in this study is divided into three phases. In the first phase, the same USDA criteria for both access and income are applied to the Hamilton County data set resulting from Reference USA (hereafter referred to as the new data set), in order to validate consistency with the USDA’s food store data. Once this consistency is confirmed, the new data set is treated as the equivalent data set that the USDA used for its report and can be used in the following analysis. In the second phase, the proposed two-step floating catchment area (2SFCA) method implemented in a GIS environment is applied to study spatial accessibility and to pinpoint tracts with low spatial access to food stores based on accessibility scores. The third and final phase combines the exact same criteria for low-income communities as the USDA uses, which ultimately indicates the locations of food-desert census tracts. In-depth comparisons are then made to examine the differences and similarities between the spatial patterns of the two resultant groups of food-desert census tracts.

This thesis is organized as follows. Chapter I introduces the research objectives and problem statement of the current study. Chapter II provides a literature review of the definitions of and research on food deserts, the concepts of food access and its related contributory factors, the key measures of food access, and issues of data challenges. The gap found in current studies on food deserts is also addressed, and this provides the foundation for the method and analysis in this research. Chapter III introduces the study area and the data source for the study. In Chapter
IV, the method for measuring spatial accessibility to food stores and a modified spatial interaction based approach for identifying food deserts are presented and proposed. Chapter V provides the results with detailed analysis and explanations, and Chapter VI concludes the findings in this study and offers recommendations for future research.
Chapter II: Literature Review

Food Deserts: Definitions and Causes

As far back as 1973, the term *desert* was first used by John Baines to describe an urban environment lacking certain facilities such as shops, churches, public houses, and social centers that foster the development of a community life (MacDonald 2005). The first application of the term *food desert* is claimed to have been coined by a resident of public housing who used it to “capture the experience of what it was like to live in a deprived neighborhood where food was expensive and relatively unavailable” in early 1990s (Cummins and Macintyre 2002a). Since then, this phrase has been widely used by policy advocates to address the issues on poverty, social exclusion, poor food retail provision and poor health, as well as by academic researchers who have attempted to quantify the food access problems and their effects on health outcomes (Cummins and Macintyre 2002a; Guy and David 2004). In the United Kingdom, food deserts were defined by the Low Income Project Team in 1996 as “areas of relative exclusion where people experience physical and economic barriers to accessing healthy food” (Reisig and Hobbiss 2000). In the report of the *Independent Inquiry into Inequalities in Health* (Acheson 1998), the term food deserts referred to inner-city areas where nutritious food at low prices is unobtainable and where many residents must rely on public transportation, and therefore lack the ability to reach out-of-town supermarkets, and consequently must depend on corner shops selling processed food. In a speech to the Annual Local Food Retail Conference in 2000, the Minister for Local Government and the Regions in Cardiff, explicitly defined food deserts as “areas that lack retail services within a 500-metre radius” (Hughes 2000). Based on that speech, Guy and David (2004) summarized five features that characterize food deserts and the populations reside in them: (1) physically disadvantaged; (2) economically disadvantaged; (3) poor nutrition/diet; (4)
geographically disadvantaged; and (5) limited food selections. They suggested that food deserts are “areas where no food retail outlets exist, or those that do exist are of unacceptable quality” (Guy and David 2004: 222). In the United States, the term food deserts appeared in the Food, Conservation and Energy Act of 2008, where they were defined as “areas with limited access to affordable and nutritious food, particularly such areas composed of predominantly lower-income neighborhoods and communities.” More recently, in the report to Congress named Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences, a food desert was defined as a low-income tract where a substantial number or share of residents has low access to a supermarket or large grocery store (USDA 2009). While definitions of the term vary across countries and studies, two components are always emphasized: food deserts are geographic areas, and residents of food deserts lack spatial and/or economic access to food stores offering a wide range of healthy food at affordable prices. However, beyond these various descriptions, there is still a lack of consensus on the definition of food deserts. Due to the open-ended nature of the term, different criteria and methodologies are applied in different research, and this practice thus impedes the comparisons among studies while raising questions on their accuracy.

Food deserts emerge in tandem with the changing geographies of food retail. Changes in food retailing have been influenced by socioeconomic and cultural shifts, and have been driven by the industrialization of agriculture, increasing economic competition and corporatization and commercial forces (White 2007). The emergence of food deserts can be attributed to both supply and demand factors. For supply factors, the development, closure and relocation of stores are direct contributory factors leading to the creation of food deserts (Curtis and McClellan 1995; Guy and David 2004). Specifically, higher construction and operating costs including rent, real
estate taxes, costs on security and less availability for parking space are the main reasons given as to why stores close and/or relocate. Establishing larger stores in uniform corporatized styles in suburban areas allows chain retailers to buy food products in bulk and sell those products at lower prices to customers who are able to shop in the same way, thereby guaranteeing much greater evenness in individual shopping patterns (Eckert and Shetty 2011). The rapid expansion of large chain supermarkets in affluent suburbs has forced smaller, independent, neighborhood grocers to close because of severe competition, simultaneously limiting food options availability for those people who relied on these smaller stores and who are most affected by the relatively high costs of time, distance and transportation in order to buy nutritious food outside of the immediate neighborhood; often these same people are the very ones reliant upon public transportation, so the closure of local food outlets and the relocation of the larger, corporate stores to the suburban fringes places undue financial, spatial and temporal burdens on them.

The predominant theory equating demand factors to food deserts is that changes in neighborhood demographics due to the growth of automobile ownership in 1950s and economic segregation begun in the 1970s have modified the customer bases in the inner-cities. Decreased median incomes among inner-city population lower the purchasing power of healthy food products, which leads to loss of profit and the eventual closure of supermarkets (Alwitt and Donley 1997). Both supply-side and demand-side explanations are implicitly assumed in the existing literatures, but it is hard to tell which singular factor is the first to occur that eventually results in the creation of a food desert. While less information is available on the reason why food deserts exist, it is reasonable to focus on the question of whether or not a food desert exists, as this question is a sensible start to approaching the problem of why they exist.
Food desert studies have raised scholarly and public awareness of the food access problem in both inner cities and low income communities. The issue of food deserts has been discussed in a variety of disciplines, including geography, public health, nutrition, business and retailing, community planning and food studies. The existence of food desert has been tested with different statistical and mapping tools but the results vary and are uniformly inconclusive. Some studies have questioned the extent of food deserts (Apparicio et al. 2007; Cummins and Macintyre 2002a; Wrigley et al. 2002; Pearce et al. 2008), while others have identified locations where food deserts do exist (Larsen and Gilliland 2008; Peters and McCreary 2008). In the United Kingdom, some studies have shown higher concentrations of supermarkets in socially deprived areas near city centers (Cummins and Macintyre 1999; Cummins and Macintyre 2002b), yet food deserts exist in suburban areas (Clarke et al. 2002; Donkin et al. 2000). In contrast, food deserts are found in urban and inner-city communities, especially where African American residents predominate (Cummins and Macintyre 2006; Gordon et al. 2011). A recent systematic review of 49 studies on food deserts in five countries from 1966 to 2007 also confirms the diversity of results (Beaulac et al. 2009). In this review study, abundant and robust evidence are found to conclude that food deserts do exist in the United States: Americans living in low-income areas, as well as those areas with concentrations of minority populations, often times overlap and tend to have poor access to healthy food. However, findings from other countries like United Kingdom, Canada, Australia and New Zealand remain sparse and equivocal: there are no firm conclusions on whether access to healthy and affordable food significantly differs between low-income areas and high-income areas. Recently, the boundaries of food desert research have expanded to callings for improvements in definitional and methodological clarity (Bedore 2010). Emphasizing the racial disparities in neighborhood food environments, Raja et al.
(2008) argued that the use of the metaphor *food deserts* is not an adequate description of the food environments in minority neighborhoods. Moreover, McEntee (2009) proposes that *food access* is a more accurate and less misleading concept than *food deserts* when it comes to describing and examining food inadequacies.

**Food Access: Definitions and Classifications**

The definition of *access* varies significantly depending on the context and most studies that have investigated the problem of food deserts are explicitly or implicitly incorporating and analyzing the concept of access. When defining access in the context of health geography, Guagliardo (2004) concluded that access can be used as a noun refers to potential for healthcare use, while as a verb refer to the act of utilizing or receiving healthcare services. When the concept is applied to the geography of food, *food access* refers to one’s ability to obtain food. The issue of food access has taken on a more nuanced meaning as researchers consider not only the food resources of households, but also their individual characteristics and the neighborhoods in which they reside (Rose and Richards 2004). Food access encompasses several intrinsic meanings: as McEntee (2010) wrote, “Food access is following a post-modern theme. People do not act logically in a robotic manner with food. Instead, food is a critical element for people to survive as well as thrive physically, culturally, emotionally and nutritionally.”

Classifications of types of food access have begun to emerge in the literature. Shaw (2006) proposed that the concept of access can be broken down into three contributory factors to problems of food access as follows: (1) Ability: physical barriers such as the physical ability of consumers and the nature landscape they need to traverse to access food; (2) Assets: economic or
financial barriers endured due to high transport costs, high prices, or the inability to afford accommodation with food preparation facilities; (3) Attitude: psychological and knowledge barriers include culturally based prejudices, a lack of cooking knowledge or unwillingness to prepare fresh food. McEntee and Agyeman (2010) elucidated the general concept of food access with three specific components – informational access, economic access and geographic access – and these three dimensions provide a comprehensive guideline for researchers to evaluate the food environments.

Informational access is determined by many factors that influence people’s food choices. These factors encompass educational, social and cultural constraints. It has been shown that one’s educational attainment and nutritional knowledge have associations with his/her consumption of fruits and vegetables. The awareness of what constituted a healthy diet was positively correlated with the level of being educated (Girois et al. 2001). However, linkages can also be affected by other subjective elements, such as personal tastes and preferences, mental desires, time constraints, and cooking skills. Social and cultural influences also play critical roles in food consumption. Brug et al. (1995) have found that consumption of fruits and vegetables was lower among those individuals with lower self-motivation and less positive attitudes. As dietary habits are a component of culture, classification of the edibility of different kinds of foods in different cultural backgrounds can greatly influence individual attitudes toward food and food selections.

Economic access refers to several financial elements that determine one’s ability to acquire food, including income level, food prices and costs of transportation, and it also considers the household’s ability to store fresh foods and the availability of cooking facilities (Shaw 2006). Economic access has been an important factor in studies that identified inadequate
food access: according to Kaufman et al. (1997), supermarkets located in either urban or rural areas charge higher prices for food than those in suburban areas due to the higher operating costs. However, the proportion of poor households is much higher in urban or rural areas compared to suburban areas. Poverty has become an important indicator of economic assess, as it is pointed out that individuals from households in poverty were more likely to exhibit nutritional deficiencies or have diets low in various nutrients (Rose and Richards 2004).

Geographic access, or spatial access, is perhaps the most popular component referred to and evaluated in the studies of food access. Access to food varies across space because of uneven distributions of food providers and consumers and geographic access is represented by the locations of food providers and the proximity from those providers to consumers. Proximity is affected by factors such as transportation availability (e.g., private/public transportation and traffic congestion) and individual travel pattern (e.g., the relative location of one’s residence and workplace) (Bitler and Haider 2010).

Besides the three different dimensions mentioned above, food access can also be classified into two broad categories – revealed access and potential access (Joseph and Phillips 1984; Luo 2004, Phillips 1990; Thouez, Bodson and Joseph 1988). Revealed access focuses on the actual utilization of food resources while potential access emphasizes patterns of distribution and aggregate supply of food. Few studies have combined assessment of potential access with an evaluation of the actual available food contents and people’s actual utilization (Block and Kouba 2006; Frank et al. 2006). In the absence of such detailed individual-level information, and because of time and financial constraints, most studies related to food assess to date focus on potential access because identifying where the underserved population are located is the essential
first step toward any effective government intervention in ameliorating the problems created by food deserts.

Even though the three components of food access are simple to understand conceptually, they are required to be operationalized by certain variables or factors that are measurable in specific studies. Instead of measuring food access via these three dimensions, studies instead differentiate spatial and nonspatial factors for food access when assessing food environments (Dai and Wang 2011). Food access varies across space and also among population groups due to different socioeconomic and demographic characteristics. Accordingly, spatial factors refer to the geographic barriers of travel time or distance between consumers and providers, whereas nonspatial accessibility emphasizes nongeographical barriers or facilitators, such as age and gender, household characteristics, socioeconomic status (e.g. income levels, unemployment rates and poverty rates), transport availability (e.g. vehicle availability, distance to public transportation stops), race and ethnicity, and culture and service awareness (e.g. education attainment or language) (Joseph and Phillips 1984; Wang and Luo 2005). Spatial and nonspatial factors interact interdependently: for instance, individuals who commute and are dependent upon public transit are largely affected by nonspatial factors such as their age, health status, or lack of car ownership, but they also tend to have to travel for a longer time/distance in their access to food resources, which thereby affects their spatial access (Dai and Wang 2011). Since food access is determined by both spatial and nonspatial factors, consideration of both of them and their interactions are required in order to achieve robust conclusions.

Previous studies have recognized that both spatial and nonspatial factors are important but their roles vary across different places and population groups (Helling and Sawicki 2003; Pearce, Witten and Bartie 2006). Hendrickson et al. (2006) found that food prices are higher but
food quality is poorer, sometimes inedible, in areas where percentages of households below the national poverty line are high. Furthermore, results from this same study suggest that food stores in impoverished areas offer the smallest quantity and variety of fresh and nutritious. Results in other studies also tend to be consistent – poor spatial access to food resources has been found in concentrated areas of minority populations and economically disadvantaged groups, and poor residents in urban areas pay more for groceries but receive poorer quality foods (Algert et al. 2006; Chung and Myers Jr 1999; Donkin et al. 1999; Guy and David 2004; Helling and Sawicki 2003; Larsen and Gilliland 2008). Explanations for the phenomena are threefold: first, costs of food in urban areas are higher because these areas are faced with increased crime rates and social insecurity: high crime rates near a store could lead to a vicious cycle in which crime deters customers and reduces sales revenues and thus increases the costs, and the common occurrences of food theft were used by the store-owners to justify the increased food prices (Hendrickson et al. 2006). Second, the issue of lack of transportation in poor households makes those residents less able to afford the costs getting to a supermarket outside of where they live in order to buy groceries at lower prices (Hendrickson et al. 2006). Third, consumer demand generally determines the types of available food products and their prices, while consumer demand is heavily influenced by personal preference, which itself is determined by individual behavior and socioeconomic factors – a general lack of education about healthy food choices leads to residents’ choice of unhealthy foods, thereby maintaining the demand for those products and perpetuating their availability. However, such results are not applicable to certain situations – African-American neighborhoods, for example, tend to have similar or even better spatial access to chain supermarkets compared with the predominantly white residential areas in Atlanta, GA (Helling and Sawicki 2003). Other studies also report that populations in socioeconomically deprived and
minority-dominant areas in inner cities have closer proximity to food stores, but cannot afford the products (Apparicio et al. 2007; Donkin et al. 1999). By contrast, results of studies on food access in the United Kingdom are mixed, suggesting that there is no clear relationship or trend that exists between food access and variables of socioeconomic or demographic characteristics (Cummins and Macintyre 1999; Cummins and Macintyre 2002a; Cummins et al. 2005). The diverse results of these studies suggest that the debate on causes and effects of food deserts continues, and that relationships between spatial accessibility and nonspatial factors vary across different areas and among different populations.

Measurement of Food Access

The analysis of food access is, most fundamentally, a study of the relationship between food providers and consumers who live in a given area (Russell and Heidkamp 2011). Assessing disparities of food access should begin with the development of sound and applicable approaches for measuring and visualizing accessibility. Since there is no singularly accepted definition of food deserts, researchers tend to shift away from the term and instead focus on measures of accessibility. A standard and widely accepted measurement of accessibility would not only enhance our knowledge of the concept, but would also permit comparisons if it could be uniformly applied among different places. Various available measures of access have been proposed to analyze spatial accessibility to food resources, four of which are the density-based approach, the proximity-based approach, the gravity-based approach and the spatial interaction approach.
Density-based Approach

The density approach quantifies the availability of food resources using buffers, kernel density estimation, and spatial clustering. One common density approach is the availability measure that calculates a rate of supply and demand within a predefined area by determining the ratio of the number of food providers to the population number within the same geographic unit. For example, accessibility can be measured as the amount of food stores within a neighborhood or a buffer zone of certain distance (service area). The unit for this method is usually an administratively defined unit, such as a census block group, a census tract, a zip code area, a city or county boundary, or a specific zone defined by the authors. This approach is popularly used in several studies (Austin et al. 2005; Block et al. 2004; Bingham and Zhang 1997; Gordon et al. 2011; Moore et al. 2008; Powell et al. 2007; Raja et al. 2008; Russell and Heidkamp 2011), and it is recommended for geographic analysis of a food environment by the Risk Factor Monitoring and Methods of the National Cancer Institute (NCI) (NCI 2011). For instance, Block et al. (2004) used a measurement of the areal density by calculating the density of fast food restaurants within both 0.5-mile and 1-mile buffers around census tracts. Powell et al. (2007) used counts of full-service restaurants and fast-food restaurants for U.S. national zip code tabulation areas in order to examine the associations between racial, ethnic, and income characteristics and the availability of food outlets. Bodor et al. (2008) used a measure of food store density, defined as the number of small stores within 100 meters of the household residence and number of supermarkets within 1 kilometer of the household to describe spatial accessibility. Gordon et al. (2011) examined neighborhood food availability and access in low-income and wealthier neighborhoods of New York City by counting the proportion of three different types of food sources (supermarkets,
small convenience stores carrying healthy foods, and fast food restaurants) within a quarter-mile of block group centroids.

**Proximity-based Approach**

The proximity approach assesses the food environment by distances or travel times. The related approaches include measurements of distance to the nearest facility, the average distance to a certain number of closest facilities, and the average number of facilities within a certain distance from a specific residence or location. Proximities are usually represented by simple Euclidean distance, Manhattan distance, or network distance via Geographic Information Systems (GIS). Proximity-based measures of access to food resources have been widely used in previous studies because of their simplicity and straightforwardness. While the proximity methods are similar, the underlying details vary in a number of ways. In particular is an issue of scale and spatial extent, for example, what constitutes a ‘neighborhood’ may have different definitions. Additionally, aggregation/disaggregation schemes vary; the lowest unit of data collection varies based on study, as does the change in geography upward to the level to which the data are aggregated and distance constructs exhibit a lack of consistency in measuring the distance from neighborhoods to food stores (Sparks et al. 2011). When proximity is used to describe spatial access, the origins representing the location of population demand vary according to different geographic entities, with the most common representations of population coinciding with either the geographic center or with a population-weighted centroid of the spatial area, though these two means are by no means the only exclusive means by which these centers can be calculated (Apparicio et al. 2007; Clarke et al. 2002; Pearce et al. 2008; Sharkey et al. 2010). In some cases, grids of population or population density are used (USDA 2009). Amalgamations or user-defined specific centers are also not unheard of: for example, Apparicio
et al. (2007) and Larsen and Gilliland (2008) used census block centroids as origins to measure distances to supermarkets, and then weighted them by population to create census-tract-level means as spatial access indicators, and Clarke et al. (2002) calculated the presence of grocery retailer within a Euclidean distance of 500 meters from postal sectors. In Smoyer-Tomic et al.’s study (2006), the network distances from postal code centroids to the nearest supermarket were calculated and weighted to neighborhood-level means by population in order to evaluate the spatial accessibility.

A desire of higher precision and availability of data precipitated the USDA (2009) to apply the 30 arc-second (approximately 1 kilometer) population grid and its grid centroids as origins in the process to measure the distance between population and food stores and the number of population, but then the total population residing outside of a 1-mile threshold distance was aggregated to the census-tract level.

The variation of methodologies across these studies raises questions regarding applicability, accuracy and comparability. Calculation of mean distances at aggregated-level units requires disaggregate data to be merged so as to form common values to represent the area’s spatial access, indicating that individual cases may be overlooked, as well as the spatial variations at the initial level. Aggregation errors also arise from the distribution of population around the centroid of spatial units, referred to as ecological fallacy, whereby data are aggregated to common values instead of representing their true values. Larger sizes of spatial units could result in serious ecological fallacy problems that populations within the analysis units are assumed to share the same spatial accessibility. Regardless of the aggregated level data being used as proxies for individuals, cautions must be taken in the interpretation of results since inferences about individuals are based solely upon on the areal data. According to Apparicio et al.
(2008), the choice of aggregation method is important: in comparison to aggregation methods using population-weighted mean as an accessibility measure for census blocks, accessibility measures computed from centroids of census tract yield significant measurement errors for 5-10% of census tracts. As spatial units vary in size from small regions (e.g., census blocks) to larger ones (e.g., census tracts), spatial accessibility measured for units in smaller size tend to be less subject to aggregation errors. Thus, finer resolution data is needed to reduce such measurement errors on the interpretation of proximity-based measures.

**Limitations of Density-based and Proximity-based Approach**

Both types of conventional approaches are straightforward and can be easily understood and implemented in understanding the spatial relationships between food providers and consumers. However, certain limitations exist. First, how realistic is it to assume that people will buy their food from the closest opportunity to them, or are they more likely to travel to an optimal store that more comprehensively meets their various needs? The concept of accessibility may expand in people’s perceptions to include additional features or amenities relating to the products to be purchased, including price of products and promotions, or the variety of food types available at one location versus another. Second, population pressure from different neighborhoods on the same food resource is not considered. Where do the people who shop at a particular store come from? Third, the size and capacity of stores, as well as other features or amenities such as parking availability or “reward points,” are not considered or differentiated. And lastly, people’s mobility, interactions between providers and consumers, and competitions among consumers and among suppliers are not taken into account.
**Gravity-based Approach**

The gravity-based approach is derived from the gravity model and accounts for both density and proximity (McGrail and Humphreys 2009). This model assumes that attractiveness of a location or a service diminishes with distance. The use of gravity model in retail environments has a long tradition that is derived from Reilly’s law of retail gravitation (Reilly 1931). The retail gravity models draw an analogy with Newton’s law of gravitation to account for shopping behaviors of customers. As larger and closer astronomical bodies have greater gravitational force, the amount of interaction between an origin and a destination is proportional to their sizes (the size of retail stores) and inversely proportional to the distance between them. When it is applied to food access, accessibility can be calculated by the weighted sum of each food provider’s attractions, depreciated by a distance-decay effect via travel friction (Lee and Lim 2009). This method addresses the issue of unrealistic assumption that people always shop at the store that is closest to them but does not solve the problems addressed by the remaining limitations mentioned previously. Additionally, difficulties in selecting or empirically determining the distance-decay function prevent researchers from using it with confidence, as the overemphasis on the decay function leads to results that are heavily spatially smoothed (Guagliardo 2004; Luo and Wang 2003). The gravity-based index is also limited in its applicability as it ignores competition among residents.

**Spatial Interaction Approach**

An accessibility measure considering supply, demand and the interactions between them is preferred when assessing accessibility, as interactions can be divided into supply competition between food providers for customers and demand competition between customers for a food resource. Such interactions are more important in rural areas where food stores are limited and
people have to travel further for grocery shopping. When the unit of analysis increases in size, the interaction between supply and demand factors becomes less problematic, but there will be more problems in spatial variation within the areal unit for analysis due to a higher aggregation level, and vice versa (Luo and Wang 2003). As an extension of the density approach, floating catchment area (FCA) methods have been developed to overcome the limitation of population-to-provider ratios (Peng 1997). Instead of using a predefined administrative boundary, the FCA method uses a floating window - a circle of some reasonable radius centered on the population centroid - to capture the ratio of physician-to-population to define accessibility. However, the FAC is characterized by a problem that it only focuses on supply factors, and ignores demand factors. A spatial decomposition method proposed by Radke and Mu (2000) have addressed this issue: a twice-conducted repeat of the floating catchment process is proposed by them, and is later incorporated by Luo and Wang (2003) in a research study of health care accessibility. This method, referred to as the two-step floating catchment (2SFCA) method, is more suitable for measuring potential spatial accessibility (Luo and Wang 2003). By using a catchment, the model explicitly considers both supplies and demands and their interactions. It discounts the availability of a supplier by the intensity of competition for its service of surrounding demands. This method has been popularly used in studies on health access (Cervigni et al. 2008; Guagliardo 2004; Luo 2004; Luo and Wang 2003; Yang, Goerge and Mullner 2006). However, the original 2SFCA assumes that access is assigned equally within a catchment. From this initial modification of FCA, an increasing number of advanced versions have been proposed, such as E2SFCA (with three different weights), whereby a catchment area is divided into three travel-time zones, or the enhanced 2SFCA that integrates a Gaussian function (Dai 2011; Luo and Qi 2009), which was developed by Guy in 1983 (Guy 1983). Additional studies on the comparison between improved
2SFCA methods and other traditional measures have illustrated the superiority of 2SFCA method (Yang et al. 2006). Since the choice of index and parameters greatly affects the final results, assumptions made through the choice of the index and parameters are required to be explicitly stated, reasonably explained, and well understood. Based on the previous effective results in identifying the disadvantaged areas of health care, the 2SFCA method has remarkable potential for measuring accessibility to food resources. However, to the best of the author’s knowledge, it has not been applied to the identification of food deserts in previous studies. Ultimately, this study employs a spatial interaction approach based on the 2SFCA method, in place of the criteria for defining a “low-access community” as provided by the USDA, so as to measure the spatial accessibility to food stores in Hamilton County, Ohio.

**Measuring the Food Environment using GIS**

In early studies about food access, GIS technologies were not utilized for major analysis purposes; instead, maps presenting basic information - such as the administrative area, number and physical distribution of food stores, population density and percentages of various about demographic characteristics by geographic unit – were common (Cummins and Macintyre 1999; Guy et al. 2004; Wrigley 2002). Application of GIS to the food environment is relatively new in public health studies, as GIS enables the modeling of proximity to food using metric distance and travel time to locations of food stores. Donkin et al. (1999) first used GIS analysis techniques to create maps of distance to food outlets over a road network, while incorporating individual food items for sale and population density. More recently, advanced GIS techniques have been applied to identify areas with low food access, and GIS has assumed an essential role in most recent studies on accessibility, not only as a tool for visualization and spatial analysis, but also as
a predecessor to quantitative and statistical analysis (Morton and Blanchard 2007; Pearce et al. 2006; Pearce et al. 2007). GIS has been used to illustrate geographic and economic dimensions of food deserts and food access (Donkin et al. 2000; Hendrickson et al. 2006; Sharkey et al. 2010). When it comes to statistical analysis, GIS is used to correlate one variable to another (for example, travel distance / time to socioeconomic characteristics). Through the application of GIS, it is also possible to capture the temporal changes in spatial distribution of food outlets and land uses, which enhance our knowledge of temporal patterns of food access. All measures of food access described previously can be realized and calculated in the GIS environment, enabling the modeling and assessment to become more efficient and accurate (Charreire et al. 2010).

Data Challenges

One of the major challenges when using GIS for studying food access concerns the quality of the available data, because the validity of GIS-based measures is largely influenced by existing data sources. As Bitler and Haider (2011) pointed out, data requirements for identifying the existence of food deserts may not be satisfied by current data sources, depending on different scales of studies. Information from standard data sources on the location and characteristics of food companies is inconclusive, with only broad industry classifications or limited details of retail types (Dai and Wang 2011; McEntee and Agyeman 2010; Russell and Heidkamp 2011). Due to the absence of information about the food contents actually available, most studies have made the assumption that proximity to supermarkets or large grocery stores can represent the access to affordable and nutritious food. However, nutrition can come from a variety of forms and can be obtained from different types of food from different types of food stores, and the food
consumption and purchasing habits of consumers may or may not include the most nutritious food products available. The limitations are well recognized in the literature on studies at a more local level: when studying food deserts in New Orleans, Rose et al. (2009) collected data of food retails from multiple sources, including obtaining data of retail food outlets from InfoUSA, on-site verification of the accuracy of certain stores, and in-store surveys and inventorying available food items. Random digit dialing and ground-truth methods with systematic on-site observations were used to determine the availability of fruits and vegetables in rural counties in Texas (Sharkey et al. 2010). However, such intensive data collection methods are impossible to archive for studies at a national scale. In the national analysis conducted by USDA (2009), two separate national-level directories of food stores were used to develop a comprehensive list of supermarkets and supercenters. One is a list of authorized stores that accept food stamps distributed by the Supplemental Nutrition Assistance Program (SNAP), and the other is a list of supermarket data from Nielsen Trade Dimensions TDLinx. Considerable disagreement across different sources of food store data has been revealed when comparing data from two national-level data sources - Dun and Bradstreet and Reference USA, and against one state-level government registry for Utah (Kowaleski-Jones et al. 2009).

Besides the discrepancies of data quality that exist among different data sets, data challenges also arise from the fact that most studies assume that the trips of food buying originate from the consumer’s residence. However, the starting point for food access varies depending on activity circles of people, the time of day in which trips to stores are made, and the presence or absence of other regular or irregular activities that people pursue. Thus, conclusions made from census data that only relegating residents to the neighborhoods does not capture the
real problems of food access. Results might be also biased due to a lack of qualitative survey analysis (Bitler and Haider 2010).

**Summary**

This review has focused on literature related to food deserts both in the United Kingdom and in the United States. The concept of food access and its contributory factors are explored and illustrated by specific findings from different studies. This review also highlights the traditional measures and some key GIS-based approaches used in existent literature of food access. Issues on the discrepancies of data sources are mentioned. Despite the progress that has been made regarding the existence of food deserts and the measurements of food access, many challenging issues still remain to be resolved: First, the lack of consensus regarding how food deserts are defined and identified contributes to the subjectivity on the choices of methodologies and the incomparability among the corresponding results. Second, either the density-based or proximity-based approaches, which are the most commonly-used measurements of spatial accessibility to food resources found in the previous literature, are limited due to the disregard of spatial interactions between the supplies and demands. Third, the use of aggregation methods in most studies leads to the inability to reveal the spatial variations of food access within aggregated geographic units (most commonly census tracts). For the assessment of local-scale food environments, data with higher resolution are needed to delineate the problem in a more detailed way.

Ambiguous phrases such as limited access, poor food retail provision, poor access and relative social exclusion, which are frequently mentioned in the definition of food deserts, have to be operationalized for specific circumstances. The extent of the problem of food deserts may
vary tremendously depending on different specific criteria. Even though the relative definitions may be appropriate for specific research purposes, planners and policymakers tend to be more interested in an absolute concept of food deserts when making decisions and interventions – where the relative concept implying that an area has less healthy and affordable food than do other areas and the absolute concept implying that an area has insufficient quantity of healthy and affordable food (Bitler and Haider 2010). To help with the determination of eligibility for Federal funds to create healthy food options, the USDA recently clarified the ambiguity of the term and released specific criteria for identifying food deserts. Using the census tract as the unit of analysis, the USDA, together with U.S. Department of the Treasury and the Department of Health and Human Services (HHS), will give funding priority to projects and interventions that seek to eliminate food deserts in those designated areas (USDA 2011). To qualify as a food desert, a census tract must meet two principal criteria:

- Poverty rate is at least 20 percent; or median family income at or below 80% of the greater of statewide/metropolitan area’s median family income; and

- At least 500 people, or 33 percent of the population in the tract, must be located more than 1 mile from a supermarket or large grocery store in urban areas (or more than 10 miles in rural areas).

This strategy utilizes an integration of the geographic access and economic access to evaluate the food access in a national scale. In particular, the measurement of geographic access applied by the USDA is a type of proximity-based method, but it is one that does not take the spatial interactions between the food stores and population into account. While census tracts in the contiguous 48 United States are evaluated based on the criteria and food-desert census tracts
are identified, to the best knowledge of the researcher, there is no scientific research evaluating the validity of results via comparisons at a local scale. Though population data at a fine resolution of 30 arc-second / 1-km square grid-based population data were used to estimate the population with low spatial accessibility to food stores, there is still space for improvement for better evaluation of spatial variation, since the study area of Hamilton County, Ohio also has a current available population grid in the higher 7.5 arc-second resolution. These findings have led to the initiation of applying a higher-resolution data to the present research study, in order to see if discrepancies are present when the measures of geographic access are improved by an advanced GIS-based spatial interaction approach. A case study of Hamilton County, Ohio is presented to assess and improve the USDA’s approach.
Chapter III: Study Area and Data Source

Judging from Feeding America’s recent hunger findings, nearly 2 million people in the United States are considered food insecure. Food insecurity is presently on the rise, and the state of Ohio has one of the highest food-insecure rates in the country at 16.4 percent. Hamilton County is the third most populous county in Ohio, with total population of 802,374 (US Census 2010), and its rate of food insecurity is above the state average – 144,580 people in the county, or 18.02% of its population, are considered food insecure (Feeding America 2009). According to a report of the Maternal and Child Health Assessment (MCHA) of Hamilton County, 13-23% of county households with children are experiencing one or more indicators of food insecurity: 23.1% of households have experienced the situation that food did not last and there was no money to get more, 19.5% of households were unable to afford balanced meals, and 13.2% households once had to cut the size of meals, or had to skip meals, because of lack of money (National Research Center Inc. 2008). Characteristics of the households prone to be vulnerable to food insecurity include the following: (1) having an income below the poverty line; (2) being headed by a single female; (3) having children under the age of 6 years old; and (4) living in the rural areas (Walker et al. 2007).

Food insecurity has become a daily struggle that demands closer attentions and constant actions for remediation. In response, several food assistance programs have been developed to improve food access of individuals and families in the United States, such as Supplemental Nutrition Assistance Program (SNAP, the formerly Food Stamp Program), the National School Lunch Program, and the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), and 59.2 percent of food-insecure households have participated in at least one of them (USDA 2009). A collaborative social movement called “WeTHRIVE!” is sponsored by
Hamilton County Public Health and is designed to promote healthy eating and physical activity in Hamilton County. The initiative started in 2010 and is continuously underway with a goal of educating people to make healthy choices by implementing policy, systems and environmental changes to support improved nutrition and to reduce obesity and other chronic diseases for the residents of the county. The initiative evokes community partners, schools, and local businesses across the county to join forces in order to implement strategies that promote food security (Hamilton County Public Health 2011). The County Public Health Department and the Nutrition Council of Greater Cincinnati, in cooperation with Mari Gallagher Research & Consulting Group, conducted a food balance study in Hamilton County in 2011 (Mari Gallagher Research & Consulting Group 2011). From several aspects, the findings of the study reveal the current situation of neighborhood food environments: (1) low healthy food access is prevalent – more than half of Hamilton County residents live in areas with low healthy food access, which means that for Cincinnati, residents live 1.5 miles or more from a mainstream food venue and for the rest area in the county, residents have to travel 3 miles or more to get to a mainstream food venue; (2) food imbalance exists – roughly 1 out of 5 residents in Hamilton County live in areas that have no or distant mainstream grocery stores but a heavy concentration of nearby fringe stores that offer fresh and healthy food; and (3) strong statistical relationships exist between the local food environment and health outcome – an increase in fringe food access correlates with more diet-related morality. It should be noted, however, that this study uses very general statistical techniques and does not take spatial traits into account. Being a focal point of food crisis in Ohio and the central metropolitan area in Greater Cincinnati, Hamilton County is thus chosen for a case study of the local food environment.
The analysis unit for this study is the census tract, which is the smallest areal unit for which all necessary socioeconomic data are collected, and it is this geographical unit that is commonly used in other similar studies on accessibility within neighborhoods (Luo 2004; Luo and Wang 2003). Census tracts are small, relatively permanent statistical subdivisions of counties that usually contain between 1,500 to 8,000 people, and they are designed to be homogeneous with respect to socioeconomic and demographic characteristics (U.S. Census 2000). Hamilton County has 230 census tracts.

For an effective comparison with the USDA’s food-desert census tracts, data for this study need to be consistent with those of the USDA analysis. Three types of data are required for the analysis: the population data, the income related data and the food store data. Since the USDA has applied the 1-km square (30 arc-second) population grid to increase the precision in measuring the number of population and their proximity to sources of healthy food, this study also used a 7.5 arc-second (approximately 180 meters) population grid, in a better resolution, available from the website of the Socioeconomic Data and Applications Center. Results at the population grid level will be aggregated to the census tract level. Income related data, obtained from 2000 Census Summary File 3, include the percentage of population living below poverty line and the median family income at census tract level.

Since the USDA does not disclose their proprietary data source of supermarkets and large grocery stores to the public, the data of food store locations in this study were obtained from the Reference USA database, an internet-based database of 14 Million U.S. Businesses. This database allows users to search for businesses by North American Industry Classification System (NAICS) codes and by geographic locations. To verify food store data, various databases have been used as means to crosscheck the final version, which include the USDA SNAP Retailer data,
online data, and other available data from the Cincinnati Area Geographic Information Systems (CAGIS) database. Based on the primary NAICS code description, food stores for this study are chosen from the category of ‘Supermarkets and Other Grocery Stores’ (NAICS Code 445110). Each individual store has available attributes including its address, longitude and latitude, SIC and NAICS descriptions, area in square footage (in ranges), employee size, actual location sales volume, and the last updated date of the record. Food stores were geocoded based on street-level latitude and longitude coordinates (Figure 3.1). According to the finalized version of the database, Hamilton County has a total of 82 supermarkets and large grocery stores. The list of food stores contains 63 chain supermarkets or grocery stores, among which are 31 Kroger stores, 6 ALDIs, 6 IGA stores, 5 Walmart Supercenters, 5 Remke Market /Bigg’s, 4 Meijers, 4 Sam’s Clubs, 1 Whole Foods Market and 1 Costco; the rest are local large grocery stores.
Since the locations of food stores plays a critical role in calculating proximity and identifying if food deserts exist, a preliminary examination of the different data set was initially conducted in order to confirm its consistency with USDA food store data. The preliminary examination followed the exact same criteria for the identification of food deserts released by the USDA, including both low-access and low income communities. Low-access communities were identified by calculating the amount and percentage of census tract populations that are more than 1 mile away from food store locations, based on the 7.5 arc-second population grids. In total, 111 of the 230 census tracts were identified, meeting the criteria of “having at least 500 or 33
percent of people that are located more than 1 mile away from food stores in urban areas and more than 10 mile in rural areas” (Figure 3.2).

Figure 3.2 Low-access census tracts (identified by the USDA’s criteria) in Hamilton County, Ohio

Meanwhile, low-income communities were selected using the criteria of “poverty rate over 20 percent or a median family income below 80 percent of the greater metropolitan area’s family income”. According to the U.S. Census Bureau, the median family income of the Cincinnati-Northern Kentucky metropolitan area was $57,800 in 2000; thus, 80 percent of that was $46,319. The result is that 103 census tracts in the county are recognized as low-income
census tracts (Figure 3.3).

**Figure 3.3** Low-income census tracts (identified by the USDA’s criteria) in Hamilton County, Ohio

Due to the lack of official numbers of census tracts in each category from the USDA, comparisons were made based on the identified food deserts. As Figure 3.4 shows, the data used for this study suggests that the spatial distribution of the identified food-desert census tracts (shaded areas) is highly similar to those defined by the USDA (areas with bold outlines), though the data source of supermarkets and large grocery stores differs. Despite this, the finalized version of food store locations in this study is consistent with the comprehensive list of food stores applied in the USDA’s analysis. This consistency underscored the validity of using food store data obtained from Reference USA to replace the original data source of USDA’s analysis.
and ensured the significance of comparisons in the follow studies. In sum, analysis in the rest of this paper is based on the 82 food stores obtained from Reference USA and population data in 7.5 arc-second population grids.

**Figure 3.4** The USDA’s Food-Desert Census Tracts vs. Food-Desert Census Tracts (identified by the USDA’s criteria) Based on Reference USA Food Stores
Chapter IV: Methodology

This chapter focuses on introducing the methods used in this study, which can be divided into four sections: (1) the first section gives a comprehensive introduction about the two-step floating catchment area (2SFCA) method that has been widely used in health geography; (2) the specific modified 2SFCA method designed for the measurement of spatial accessibility to food stores in the current study is introduced; (3) a comparison and contrast between the 2SFCA method and the approach applied by the USDA towards spatial accessibility is discussed; (4) combined with the same criteria for measuring the economic access, the modified spatial interaction based approach for identifying food deserts is presented.

Two-Step Floating Catchment Area (2SFCA) Method

The original two-step floating catchment area (2SFCA) method, first proposed by Radke and Mu (2000) later employed by Luo and Wang (2003), is a special case of an improved gravity model, but is more intuitive to interpret as it uses a special form of supply-to-demand ratio (Luo and Qi 2009). The 2SFCA method has been used in a number of recent studies measuring health care accessibility (Guagliardo 2004; Langford and Higgs 2006; Wang and Luo 2005; Yang et al. 2006), and the method is implemented in two steps as follows:

Step 1: For each location of health care provider \( j \), search all population locations \( k \) that are within a threshold travel distance \( d_0 \) from location \( j \), which forms a catchment area of location \( j \), and compute the physician-to-population ratio \( R_j \), written as Equation (1):

\[
R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k}
\]
The parameters are defined as follows: \( P_k \) is the population at location \( k \) having its centroid falling within the catchment area from location \( j \) (i.e. \( d_{kj} \leq d_0 \)); \( S_j \) is the number of physicians at location \( j \), which represents the capacity of health care providers; and \( d_{kj} \) is the travel distance between \( k \) and \( j \).

Step 2: For each population location \( i \), search all locations of health care providers \( (j) \) that are within the threshold travel distance \( (d_0) \) from location \( i \), and sum up the physician-to-population ratios which were generated in step 1 \((R_j)\), to obtain the spatial accessibility at \( i \), written as Equation (2):

\[
A_i^F = \sum_{j \in \{ d_{ij} \leq d_0 \}} R_j = \sum_{j \in \{ d_{ij} \leq d_0 \}} \left( \frac{S_j}{\sum_{k \in \{ d_{kj} \leq d_0 \}} P_k} \right)
\]

Here \( A_i^F \) represents the accessibility of population at location \( i \) to physicians, and the larger value of \( A_i^F \) indicates better access to health care providers at that population location. The first step measures physician availability for the supply location, while the second step measures the spatial accessibility for the demand location. This method considers interactions between physicians and patients and computes an accessibility measure that indicates the spatial variation across administrative boundaries.

Measuring Spatial Accessibility to Food Stores via a Spatial Interaction Approach

When the 2SFCA method was used in previous studies, the analysis units were census tracts and the proxies for the locations of demand population were population-weighted centroids of census tracts. Unlike previous work, this research uses the centroids of population grids to
represent the demand locations. The grid data were derived from the U.S. Census data by taking population and housing counts at the census block level and proportionally allocating the counts to a latitude-longitude level (SEDAC 2000). The resolution for the grids is 7.5 arc-seconds, which is approximately 180 meters. Using the regular grid cell in raster data can increase the precision of food access measurement while minimizing the aggregation errors, and it is a preferred method for comparisons with the USDA’s approach in the successive steps.

Luo and Wang first introduced the conventional 2SFCA method in 2003, and since then it has been improved by studies related to measurement of spatial accessibility in health. For example, a kernel density function (Guagliardo 2004) or a Gaussian function (Dai 2010) has been introduced to acknowledge the continuous distance decay effect within the catchment size. Luo and Qi (2009) applied weights to differentiate travel time zones to model the distance decay effects in a discrete fashion. However, the debates on which function to choose and what parameters to use still prevail in studies on health accessibility. Moreover, it has been argued that the spatial patterns of the estimates will not be significantly affected by the different functional forms for determining distance decay weight (Luo and Whippo 2012). When 2SFCA method is introduced to measure food environments, several considerations are made. First, in general, for any given area, the density of food stores is likely higher than health care centers. For example, Hamilton County has nine hospitals but 82 supermarkets or large grocery stores, and health clinics tend to be more clustered than food retailers. The spatial pattern of food stores is different from that of the health care centers, and therefore so is the distance-decay pattern between the supply and demand factors. When the catchment size indicating the service area of food stores is much smaller (i.e. 1-mile for catchment radius compared to 30-minute travel zone for the catchment of physician location), the distance decay effect within catchment area of food stores
is not as strong as that of health care centers (Wang and Luo 2005; Luo and Qi 2009). Second, the appropriate functional form for distance decay weights has not been designed as yet for food access, so detailed surveys of actual spatial behaviors of grocery shopping are may be required for greater confidence. Third, the values of accessibility scores are not intuitive and are less comparable with the incorporation of different functions. For example, accessibility scores generated by the conventional 2SFCA indicate physician availability that are reachable from each residential location, which translates as the number of physicians that can be shared per resident at each location. However, when functions accounting for distance decay effect are introduced, the level of accessibility for each residential location is difficult to determine without comparison to accessibility scores for other locations. Based on these concerns, and for the purpose of addressing the problem of food access in a simple and understandable manner, this study begins with the conventional 2SFCA method, and then makes some adjustments to its application of measuring spatial accessibility to food resources.

When 2SFCA method is applied to measure food accessibility, some changes need to be made. According to equation (1), the number of physicians at location $j$ is represented by $S_j$ as a proxy indicator of the capacity of the health care centers. Capacities of health care centers vary because of their different number of available physicians. However, when focus is pinpointed only on the supermarkets and large grocery stores, the capacities of food stores are assumed to be the same in this study. The modified 2SFCA method works as follows:

At step 1, for each food store location $j$, search all population grid centroids within a threshold travel distance $d_0$ from location $j$, and compute the ratio $R_j$, written as Equation (3):

$$R_j = \frac{1}{\sum_{k \in \{d_{kj} \leq d_0\}} p_k}$$  \hspace{1cm} (3)
Here $P_k$ is the population in grid $k$ that falls within the catchment area from food store location $j$ (i.e. $d_{kj} \leq d_0$). This step assigns an initial food store-to-population ratio to each food store location, which is the inverse of the total number of residents served by the food store.

At step 2, for each centroids of the population grid $i$, search all food store locations ($j$) that are within the threshold travel distance ($d_0$) from location $i$, and sum up the ratios which were generated in step 1($R_j$), to obtain the spatial accessibility at $i$, written as Equation (4):

$$A_i^F = \sum_{j \in \{d_{ij}\leq d_0\}} R_j = \sum_{j \in \{d_{ij}\leq d_0\}} \left( \frac{1}{\sum_{k \in \{d_{kj}\leq d_0\}} P_k} \right)$$

In this equation, $A_i^F$ represents the accessibility of residents at population grid $i$ to food stores, and a larger value of $A_i^F$ indicates a better spatial access to food stores at that population location. Instead of merely focusing on the demand side as the USDA method does, this method considers the supply side and the interactions between supply and demand. The capacities of food stores are discounted by the competition for its products from the surrounding demands.

The modified 2SFCA method generates the score of spatial accessibility for residents in each population grid. In order to make it possible for the identification of low-access areas at the census tract level, these scores need to be aggregated by tract units, so a weighted mean of scores of spatial accessibility for each census tract is calculated to serve that purpose. For each population grid, its score is first multiplied by its population ($P_j$), and then summed with products of other grids that fall within the same census tract. This sum is then divided by the total population of the census tract in order to obtain the score of spatial accessibility for each census tract (Equation (5)).
\[
\overline{A^F_w} = \frac{\sum_{i=1}^{n} P_i A^F_i}{\sum_{i=1}^{n} P_i}, \text{ where } n \text{ is the number of population grids within each tract.} \tag{5}
\]

Based on the weighted-mean scores of spatial accessibility, low-access census tracts can be identified. Since nearly half of the census tracts (111 out of 230) are identified as low-access communities according to USDA criteria in the preliminary examination process, the modified measure applies the median value as the specific cut-point to identify census tracts with relatively low spatial accessibility to food stores. In statistics, the median is described as the middle value that separates the higher half of a set of data from the lower half, and one of its desirable properties is that it is not severely affected by outliers (Wong and Lee 2005), and in non-parametric statistics, median is often used to indicate location. As a result, low-access census tracts are identified as those census tracts whose scores of spatial accessibility to food stores are lower than the median score of Hamilton County.

**Spatial Interaction Based Approach for Identifying Food Deserts**

The food desert issue is not simply about spatial accessibility to food resources; it has been proved that socioeconomic status of the population also characterizes and influences the built food environment. Economic access, together with social and cultural influences are equally or more important (Guy and David 2004; McEntee and Agyeman 2010). However, these factors are rather complicated and there is no clear agreement on what indicators are relevant and representative. Socioeconomic status cannot be related to one particular characteristic, but more often is indicative of an accumulation of many indicators (Apparicio et al. 2007). The levels of effect on the socioeconomic status for different indicators are hard to determine among different
study areas. Since the focus of this study rests on the measurement of spatial accessibility to food stores, the method for measuring economic access of the study area is chosen to be consistent with USDA criteria. In summary, the designation criteria for identifying the food deserts are as follows:

- To qualify as a low access census tract, the score of spatial accessibility to food of the tract should be lower than the median score of spatial accessibility of the county area;
- To qualify as a low income census tract, the poverty rate of the tract is at least 20 percent or the median family income does not exceed 80 percent of the area.

The USDA applied 1-mile (urban) and 10-mile (rural) straight-line buffers to define the service areas for supermarket and large grocery stores. Thus, similarly, scores of spatial accessibility are measured based on the results of the 2SFCA method using one-mile catchment areas. Following the new designation criteria, the food-desert census tracts are re-identified by the spatial interaction-based approach in this study. The spatial distribution of the re-identified food deserts is then compared to the original ones officially released by the USDA. Conclusions on the evaluation of the USDA’s approach are drawn based on the discrepancies and similarities between the two results.

The visualization of maps and measurement of spatial accessibility via the 2SFCA method is implemented in a GIS environment using the ArcGIS 10.0, the statistical analysis and data processing are conducted using Microsoft Excel 2010 and IBM SPSS Statistics Software Version 18.
Chapter V: Data Analysis and Results

This chapter focuses on the display and analysis of results derived from the methodologies. As a case study, the suggested modified approach for the identification of food deserts is applied to Hamilton County, Ohio, where certain neighborhoods have been suffering from food insecurity. Disparities in spatial accessibility to supermarkets and large grocery stores measured by the modified 2SFCA method are shown via choropleth mapping. The re-identified food deserts by the spatial interaction approach are compared with the original food deserts released by the USDA, implying both similarities and discrepancies between results derived from the two measurements. The critical problems of the arbitrary criteria used by the USDA are unveiled based on the investigation of reality.

Spatial Variations of Accessibility to Food Stores

A catchment size of one mile is chosen when the 2SFCA method is applied to the study area. Ideally, the catchment size should be determined by the food stores’ attractiveness and customers’ perceptions of travel impedance. Attractiveness of food stores varies across different types of food stores and the perceptions vary among people with different ages, races, ethnicities, and cultures, so an objective determination would require extensive surveys. The size of a catchment area determines the service area of food stores and the distance that the demand population would like to travel to obtain food. For populations with vehicle ownerships, it is reasonable for them to travel further to get the optimal food products. As the searching radius gets larger, more food suppliers will be available to meet the demand, while the increasing catchment area size indicates larger service areas for food stores, which means that the
availability of food stores are discounted by more intensive competition from the enlarged demands. However, this study only focuses on the walking distance from residential locations to food stores. Given the USDA applied 1-mile as the searching radius from the food stores, this study uses the same value for catchment size in order to make the results comparable. The results of scores of spatial accessibility to food measured by 2SFCA method are shown in Figure 5.1.

**Figure 5.1** Spatial accessibility to food stores in Hamilton County, Ohio by the 2SFCA method, for 1 mile catchment area.
Table 5.1 Descriptive statistics of scores of spatial accessibility for 1-mile catchment area.

<table>
<thead>
<tr>
<th>Access Score</th>
<th>Min</th>
<th>Max</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Mile Access</td>
<td>0</td>
<td>0.6880</td>
<td>0.0673</td>
<td>0.0936</td>
<td>0.0924</td>
<td>2.120</td>
<td>8.236</td>
</tr>
</tbody>
</table>

Note: the scores of accessibility have been multiplied by 1000

Table 5.1 shows the descriptive statistics of scores of spatial accessibility generated by the 2SFCA method with 1 mile catchment area. These scores are multiplied by 1000 to get a larger absolute number for the following explanations. The mean accessibility score of 0.0936 indicates that the average number of shared food store is 0.09 per 1000 resident in the county. The availability of food stores in the census tract with highest spatial accessibility to food is 0.69 per 1000 resident. The statistical distribution of the scores is positively skewed, as most census tracts have spatial accessibility lower than the mean access of the county. As it can be observed from Figure 5.1, in general, the spatial accessibility to food is quite low in the rural areas, which are located in the northwestern and southeastern areas. It seems impossible for residents in these neighborhoods to get fresh food without vehicles. Notice that the inner city areas, which located in the south central part of the county, are recognized as the low access areas to food. While the USDA only considers the proximity to food stores in terms of spatial accessibility, census tracts around the downtown areas were not defined as low-access communities for the reason that there is a supermarket located within 1-mile distance. The size of census tracts in the inner city is much smaller than those in suburbs or rural regions. Thus they can be easily covered by the one-mile service areas, even if there is only one supermarket or large grocery store nearby. However, proximity cannot be the only proxy for food access, especially for those census tracts with large population but small area size. The availability of food products including the range and quality
of food items may be discounted for the high demands. The food access might be easily overestimated without consideration of the competitions from the surrounding demands.

The northern areas in the county tend to have much better spatial accessibility to supermarkets or large grocery stores, especially the area around the primary highway junction of I-275 and I-75. As chain supermarkets or large grocery stores prefer to locate in the sites which cost lower operation expense but guarantee higher return on investment, the wealthy suburban neighborhoods are desirable sites. However, food access of certain areas in these neighborhoods might be underestimated when there are agglomerations of food stores located in areas with sparse residence. When supermarkets are located in high proximity with each other, their service areas are quite similar. In this case, food access might be underestimated if the majority of population resides outside the union of individual service areas. In fact, the service areas for these types of agglomerations are doubled or tripled according to their attractiveness and influences on the surrounding neighborhoods.

Low-access census tracts are identified based on the scores of access obtained by the 2SFCA method with one-mile catchment area. Census tracts with lower than median access score are identified as the low-access census tracts (Figure 5.2).
Figure 5.2 Low-access census tracts (identified by the 2SFCA method) in Hamilton County, Ohio.

Compared with the previous map of low-access census tracts identified by the USDA criteria, discrepancies on the spatial pattern are obvious. The northeastern regions, which were identified as low-access census tracts using the USDA criteria, are categorized to the higher half with relatively good spatial accessibility based on the 2SFCA method. Similarly, census tracts in the western adjacent regions to the City of Cincinnati are grouped together as areas with relatively good spatial accessibility, due to their lower density of population but with a reasonable number of supermarkets located nearby. Meanwhile, the inner city, where almost none of the census tracts has population located out of the one-mile buffer from the only existing
supermarket, are then identified as low access areas considering the intense competitions from the demand side via the 2SFCA method.

Consistencies exist in the southeastern part of the county, where neighborhoods are characterized by high proportions of white residents and households with relatively high income levels. Since fewer primary highways pass through these regions and vehicular ownerships tend to be higher, it makes sense that spatial accessibility to food resources is low in these areas (See Figure 5.3). Additionally, certain census tracts in the northern part within the City of Cincinnati, where the population is predominantly African-American, are identified as low-spatial-access communities by both methods. In other words, when we focus only on the demand factors, or when we take into account the interactions between supply and demand, these areas of low food access emerge due to the large amount of demand populations and the occurrence of fewer numbers of supermarkets / large grocery stores situated at greater distances.
Food Deserts Defined by the Spatial Interaction Based Approach

Food desert census tracts are finally identified based on the combination of criteria for spatial access and economic access (See Figure 5.4). Areas shaded in gray are the food deserts identified using the modified approach proposed by this research, and areas in bold outlines are the food desert census tracts officially released by the USDA. Overall, considerable agreements between both results are found. The overlapping areas are respectively located in the northern and southwestern part in the City of Cincinnati, and southeastern region of the county. Compared to the spatial pattern of the USDA’s food deserts, the re-identified food deserts based on the
proposed method tend to be much more clustered and occupy larger areas. It is noticed that the only census tract located in the north, which was defined as a food desert by the USDA, does not meet the criteria based on the spatial interaction based approach. Also, more census tracts in the inner city and uptown areas are identified as food deserts in this study.

![Food-Desert Census Tracts in Hamilton County, Ohio](image)

**Figure 5.4** The USDA’s food-desert census tracts V.S. food-desert census tracts (identified by the spatial interaction based approach) based on Reference USA food stores.

Taking account of the distribution of supermarkets and population data, explanations for the discrepancies are stated as follows. First, in the case that when supermarkets are spatially located as clusters, following the logic of the USDA criteria for low access communities, it can be perceived that the combined service areas of two stores might not capture a significantly
greater number of people when compared against an area with only one supermarket. Take the example of the food desert census tract in the City of Springdale (Figure 5.5), with two supermarkets located closely within this area. Two clusters of population, one in the northeastern part of the tract, and the other in its southwestern corner, are found. However, since more than 33 percent (39.9%) of population resides greater than 1 mile away from the supermarkets, and the median family income ($43,340) of the tract is lower than 80% of the median family income in the larger metropolitan area, this census tract is defined as a food desert by the USDA. However, when the interactions between the demand populations and food suppliers are considered within the service areas (the 1-mile buffers), people residing in the overlapping areas do in fact have better food access and thus help to increase the population-weighted mean of the overall accessibility score of the census tract. For each census tract, the higher proportion of people within the overlapping service areas of supermarkets would lead to the higher overall score of spatial accessibility to food stores. That is the reason why the census tract in the City of Springdale is not qualified for a low-access community, and not even a food desert. Secondly, food access might be overestimated in areas with high population density, with census tracts located in the inner city and uptown areas as the most pertinent examples of this. Even with close proximity to supermarkets or large grocery stores, the food access in these census tracts are discounted by the high pressure from competitions for the food products among demands in the surrounding neighborhoods. Notice that there remains a void area between two food desert census tracts identified by the USDA’s approach in the neighborhood of East Price Hill and West Price Hill, where contains four small census tracts (Figure 5.6). Although these census tracts are almost all completely located within the one-mile service area, the large amount of demand and the limited food supply lead to their relatively low scores of spatial accessibility to food stores.
As the Figure 5.6 shows, a total of 23,318 people are located within the one-mile service area from the only food store nearby. Taking account of their low median family incomes, these areas are treated as food deserts by the proposed method in this research. When it is linked to the reality based on field observations, the results become more reasonable. Located in the Lower Price Hill community, these census tracts are predominated by low-income African American and Hispanic residents. Most of the residents do not have transportation to shop in other communities and thus all depend on the only available food store that is within walking distance. However, the only accessible Kroger store located at the incline district is offering limited variety of fresh food items and can hardly satisfy the intense demand. With all these concerns in terms of local situation, special attentions should be paid to these areas that are re-identified as food deserts by the spatial interaction based approach.

Overall, the discrepancies are caused by two main limitations existing in the USDA’s approach: 1) the agglomerative effect of closely located food stores are not considered when proximity is the only indicator of spatial accessibility, which leads to the underestimation of food access of those areas where clusters of food stores exist; 2) the unrealistic assumption of unlimited supply capacity of a food store will overestimate the food access of areas with high population density but limited available food stores nearby.
Figure 5.5 A census tract identified as food desert by the USDA approach, but not by the spatial interaction based approach.

(Note: The discrepancy is caused by USDA approach's disregard of the agglomerative effect of two closely located food stores.)
Figure 5.6 Census tracts identified as food desert by the spatial interaction based approach, but not by the USDA approach.

(Note: The discrepancy is caused by USDA approach's unrealistic assumption of unlimited supply capacity of a food store to a large population.)
Chapter VI: Conclusions and Future Research

Food deserts, by definitions, are a matter of not only spatial access but also of economic and social access. The concept is under continuous refinement and receiving intensive attentions from a variety of different social science disciplines. As food access varies across space as well as socioeconomic dimensions, there is a lack of unity on the definition of food deserts and the required measures for identifying them, thereby contributing to the current debate on their actual existence (Walker et al. 2010). As McEntee (2009) pointed out, since we have no singular definition of food deserts, our focus should shift from defining the term to measuring food access. There have been lots of efforts to quantify the concept utilizing various discipline-specific approaches. The specific definition of food desert and the detailed criteria for its identification released by USDA, to some extent, do provide standard guidelines and official reference for policy makers to make decisions for local community development in an easier way. However, those specific cut-points delineating when food access is defined as “low” raise questions as to whether or not these criteria are objective and if they actually reveal the actual problem of food deserts in the local food environment.

The purpose of this study is to evaluate and improve the USDA criteria for identifying food deserts. Inspired by the methods used to examine health access, this paper applies a spatial interaction approach – the two-step floating catchment (2SFCA) method to measure the spatial accessibility to food stores (Luo and Wang 2003; McGrail and Humphreys 2009; Wang and Luo 2005). Based on the results generated by the 2SFCA method, the criterion that “to qualify for a low access community, a census tract should have a score of spatial accessibility to food stores that is lower than the median accessibility score of the greater area” replaces the original criteria defined by the USDA to identify the low-access census tracts. The original method suggested by
the USDA to measure the spatial accessibility basically focuses on the proximity. Proxy for spatial accessibility for each census tract is the amount of population (or percentage of population) that resides more than one mile from food sources. Merely focusing on the demands (the population) might generate biased results that overestimate or underestimate the actual spatial accessibility. In contrast, the 2SFCA applied in this study considers not only the demand populations and food suppliers, but also the potential interaction between the two sides. While populations residing within the service areas of the food stores are considered to have access to food, the availability of food stores in return might be discounted by the intensive demands. In this case, results generated by the 2SFCA tend to more accurately reveal the ground-truth reality.

The advantage of better spatial accessibility sometimes may not represent the true convenience of food access when the socioeconomic disadvantages remain as barriers to the mobility and affordability. Thus, the criteria taking account of economic access by the USDA is reasonable when it is applied to identify the food deserts. Since there is no agreement on the indicators for the social deprivation, this study adheres to the same criteria as the USDA when assessing economic access of census tracts. This also helps to increase the effectiveness of the comparison of the final results.

Based on the discrepancies and similarities found during the comparison in the case study of Hamilton County, Ohio, it can be concluded that methodological limitations do exist in the USDA’s approach for identifying the food deserts. USDA criteria lack robustness when they are applied to assess the local food environment. Specially, the criteria for identifying census tracts with low access are arbitrary – the measure can overestimate the spatial accessibility of those compact tracts with large population but underestimate the spatial accessibility of tracts with agglomerations of food stores nearby. The modified spatial interaction based approach presented
in this study informs ongoing uncertainty about how spatial accessibility to food stores can be measured.

Even though previous studies use several methods to measure food access and investigate the existence of food deserts based on certain standards, to the best knowledge of the author, no scientific research has ever compared their final results with the official food-desert census tracts released by the USDA at a local level. The modified approach for identifying the food deserts proposed in this study and the results of comparison contribute toward the development of a method for the identification of food deserts in the following ways:

1) The inconsistencies between the re-identified food deserts and those identified by the USDA reveal the lack of robustness of the USDA’s approach;

2) The GIS-based 2SFCA method can improve the measurement of spatial accessibility by considering the potential interactions between food supplies and demands;

3) The modified spatial interaction based approach inheriting the principles of 2SFCA method and the USDA criteria is applicable to other local food environment.

It should also be noted that findings from this study may be subject to several limitations. First, the accuracy of this study, to some extent, might be discounted by the utilization of a different data source of supermarkets and large grocery stores. Due to the unavailability of the data source used by the USDA, a preliminary examination on the validity of the data used in this study is required. Based on the results of food deserts identified by the USDA criteria using the new data set from Reference USA, the two data sets are not 100% matched. However, the accuracy may also be improved by using the population grid in a higher resolution.
Second, several limitations exist in the 2SFCA method. While this study uses the 2SFCA method to evaluate the spatial accessibility, Euclidean distances are measured to represent proximity, and the service areas of supermarkets and large grocery stores might be exaggerated. As with other studies on spatial accessibility, as the size of catchment area increases, results near the borders of the study area need to be interpreted with caution due to edge effects. Food stores outside of the study area should also contribute to the spatial accessibility to food of demands, or populations that are located near those artificial borders. This problem can be solved by the availability and incorporation of data in the adjacent areas into the study. Another major limitation of the 2SFCA method is the assumption of uniform spatial behavior of subjects commuting between the origins and destinations. Based on the dichotomous travel impedance that is predefined by individual travel threshold or the service area, population within the catchment are assumed to have equal access to the food stores located inside the same area, while the spatial accessibility of population outside of the catchment area is zero. The problem of the equal access assumption can be addressed via the incorporation of the gravity model to account for the distance decay within the catchment area.

Third, although the research has used a one-mile catchment area to remain consistent with USDA criteria in a reasonable way, this buffer is still a somewhat arbitrary parameter. While some residents are able to travel farther for food, for others a one-mile distance might be a hardship. Considering the uneven distribution of population and food stores in urban and rural environmental settings, an avenue for future research is to conduct a stratified analysis based on different environmental settings or to introduce an adaptive bandwidth to evaluate spatial accessibility.
Fourth, all supermarkets and large grocery stores are assumed to have the same capacity of service. However, in reality, the attractiveness of food stores varies depending on their sizes, available food items, prices and quality of food and their advertising and promotion strategies. In addition, sources of healthy and nutritious food should not be limited to supermarkets and large grocery stores; other food retailers such as fruit and vegetable shops or specialty stores may also offer a range of healthy food products. For example, the Findlay Market as the primary source of fresh, local food in the region was not identified by the data source, while those supercenters like Sam’s Club or Costco, even identified as supermarkets, are inaccessible to population without memberships. For future studies, more types of food stores and interactions among these food venues need to be incorporated in order to gain a comprehensive understanding of the real food environment.

Fifth, both the spatial interaction based approach proposed in this study and the USDA criteria are designed to measure the potential food access of the census tracts. The identified food desert census tracts are not verified with qualitative research to learn about realized access. Future research need to undertake interviews with residents to gain a better understanding of their perception towards grocery shopping and behaviors of food consumption to obtain more reasonable parameters used in the measurement, and thereby improve the criteria for identifying the food deserts.

Despite these limitations, this study demonstrates that methodological limitations do exist in the USDA’s specific criteria for identifying the food desert census tracts. Using a GIS-based 2SFCA method to measure the spatial accessibility in a different way, this study encourages the consideration of interactions between demand population and food supplies when defining the spatial accessibility to food resources. The method is simple to implement in a GIS environment
and the improved criteria for the definition of low access proposed by the spatial interaction based approach is more objective based on its reference to the overall spatial accessibility in the study area and its comparative placement compared to the median level. Discrepancies found in the re-identified food desert census tracts suggest the necessity for the USDA to improve its specific definitions of food deserts in order to better reveal the reality. Overall, this study contributes to the literature on food deserts by a critical evaluation on the USDA’s definition of food deserts as well as the improved specific criteria for identifying their existence in the United States.
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