Providing A New Low-Cost Primary Care Facility for Under-Served Communities: A Site Suitability Analysis for Service Planning Area 6 in Los Angeles County, California

by

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To my family

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List of Abbreviations

2SFCA	2-Step Floating Catchment Area
GIS	Geographic information system
GTFS	General Transit Feed Specification
MAUP	Modified Areal Unit Problem
OECD	Organization for Economic Cooperation and Development
SPA	Service Planning Area
SPM	Supplemental Poverty Measure

Abstract

Primary care is crucial for both individual and public health outcomes. However, access to primary care remains insufficient for low-income populations even in developed countries like the United States. Striving to contribute to tackling this problem, this thesis provides a site suitability analysis for a new low-cost primary care facility in Service Planning Area 6 (SPA6) of Los Angeles County, a significantly under-served area that largely coincides with South Los Angeles. This thesis first employs fuzzy overlay analysis to evaluate candidate sites with a series of criteria including proximity to public transit, distance from existing low-income primary care facilities, appropriate zoning, an empty or under-utilized parcel, relatively cheap land cost, and relatively large low-income population. This thesis evaluates a short list of candidate sites resulting from the fuzzy overlay analysis by calculating their impacts on the primary care accessibility scores of each census tract in SPA6 using the 2-Step Floating Catchment Area method (2SFCA). The 2SFCA method quantitatively assesses primary care accessibility using floating catchment areas calculated based on travel time at population points and primary care provider points. To account for relatively low car-ownership rates among low-income populations, this thesis adopts a novel approach that defines the floating catchment area as the intersection of the two catchment areas: one defined by a 30-minute travel time via public transit and one defined by a 30-minute travel time via private vehicle. The final results from the fuzzy overlay and the 2SFCA analyses provide a list of suitable candidate sites with various geographical and physical attributes ranked by their accessibility scores, providing an informative, flexible, and intuitive guideline that caters to the different needs of potential decision makers looking for a site for a new low-cost primary care facility that would improve primary care accessibility in SPA6.

Chapter 1 Introduction

Access to affordable primary medical care should be a universal human right. However, the reality of primary care provision and accessibility is less than ideal, especially for low-income communities. The communities collectively known as South Los Angeles face a variety of unfortunately common inner-city problems including inadequate provision of public services. Primary health care is the entry point to the health care system; it provides essential curative and preventive care to the public, and is thus crucial for both individual health and public health conditions. The Los Angeles County Department of Health Services divides the county into eight management regions, called Service Planning Areas (SPAs). South Los Angeles largely coincides with the Department of Health's SPA6. Department of Health data reveals that SPA6 suffers from a severe shortage of primary care provision in general and low-cost primary care provision in particular.

Los Angeles County, private health care providers, and community service nonprofits have been striving to improve affordable primary care provision for the communities within SPA6. This thesis supports this work by identifying a suitable site for a new low-cost primary care facility in SPA6. Since low-cost primary care provision usually depends at least partially on public funding, it is crucial to carefully select a site for a new affordable primary care facility so that it could serve as many residents in need with as little tax payer money as possible. Therefore, this thesis is significant as it provides suggestions for selecting a suitable site for a new primary care facility that takes into consideration the socioeconomic conditions of SPA6 and maximizes the improvement of affordable primary care access with limited resources. This result of this project could be implemented by Los Angeles County government or private entities that are working to improve affordable primary care for the communities in South Los Angeles.

In addition to the practical contribution discussed above, this thesis contributes to the literature on site suitability analysis for primary care facilities with a novel methodological approach that incorporates a quantitative evaluation step to assess the candidate sites. This thesis adopts fuzzy overlay analysis to rank all candidate sites based on a set of general site selection criteria for primary care facilities as the first step of the site suitability analysis. This thesis then evaluates the top candidate sites by calculating the impacts of each on the primary care accessibility using the 2-Step Floating Catchment Area (2SFCA) method. The addition of the 2SFCA method adds a level of depth to the site suitability analysis because it verifies the suitability of the candidate sites by providing intuitive accessibility scores generated from empirical data, and it makes this approach a novel addition to the scholarly literature.

1.1. Motivation and Study Area

Los Angeles County is a large county both in terms of geographical size and population. Los Angeles County Department of Health Services divides the county into eight SPAs in order to better develop and provide health care services based on the needs of residents in different areas. The study area of this thesis is SPA6 and surrounding communities. SPA6 includes the communities of Athens, Compton, Crenshaw, Florence, Hyde Park, Lynwood, Paramount, and Watts, which are also collectively known as South Los Angeles. This section describes the socioeconomic level of South Los Angeles and then compares the socioeconomics and health care provision in SPA6.

1.1.1. South Los Angeles

Despite the fact every human being should have access to health care, the lack of access to affordable primary care is severe in SPA6. As one of the eight SPAs of Los Angeles County, SPA6 geographically coincides with South Los Angeles. Figure 1 below shows SPA6 and South Los Angeles.

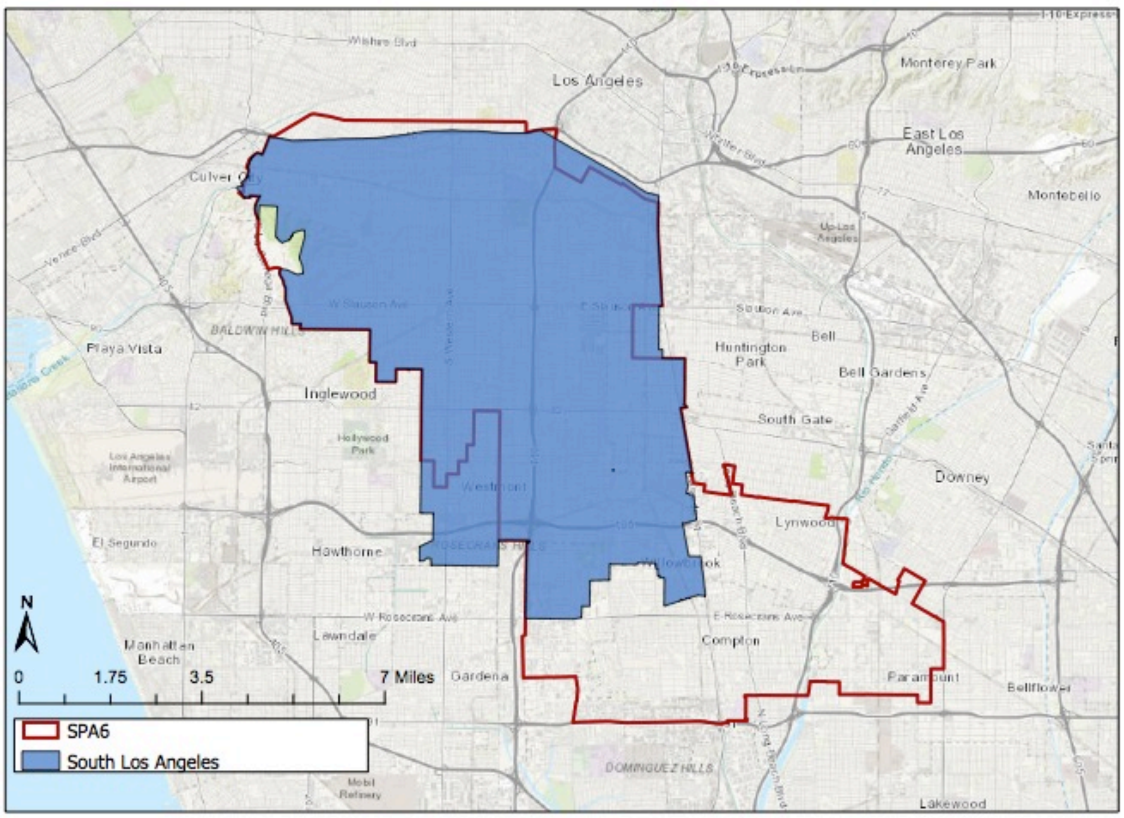

Figure 1. SPA6 and South Los Angeles

In comparison to the county average, South Los Angeles has fewer health care facilities, a smaller health care workforce, and less health care financing, health care coverage, and primary care access (Park, Watson, and Galloway-Gilliam 2008). Furthermore, South Los Angeles is below the county average in terms of nutrition, physical activity options, public safety, housing, and education (Park, Watson, and Galloway-Gilliam 2008). Table 1 below shows the disparities in health care resources and other basic resources in South Los Angeles in comparison with the county average.

Table 1. Disparities in Health care Resources and Other Basic Resources: South Los Angeles Compared to the Los Angeles County Average

Types of Resources	Resource Items	South LA (Percent Difference Compared to LA County Average)
General health care	Health care facilities	-28%
	Health care workforce	-76%
	Health care financing	-65%
	Health care coverage	-30%
Primary care	Primary care access	-34%
	Primary care utilization	-24%
	Percent of adults who reported having a regular source of care	-7%
	Percent of adults who reported easily obtaining medical care	-18%
	Percent of adults who could not afford dental care at least once in the past 12 months	-36%
	Percent of households with vehicle	-68%
	Percent of ER hours spent in diversion a year	-90%
	ER visits that leave without being seen per 1,000 population	-12%
Other Basic Resources	Nutrition	-106%
	Physical Activity Options	-55%
	Public Safety	-17%
	Housing	-40%
	Education	-43%

Data Source: Park, Watson, and Galloway-Gilliam 2008

1.1.2. Service Planning Area 6 in Los Angeles County

Health care provision for communities of South Los Angeles is managed at the county level by the Los Angeles Department of Health SPA 6. As noted, the study area for this project is SPA6. The analysis herein also considers the neighboring SPAs to SPA6 to avoid edge effects where SPA6 residents may prefer to travel across SPA boundaries to seek health care. Figure 2 below shows the eight SPAs in Los Angeles with SPA6 highlighted.

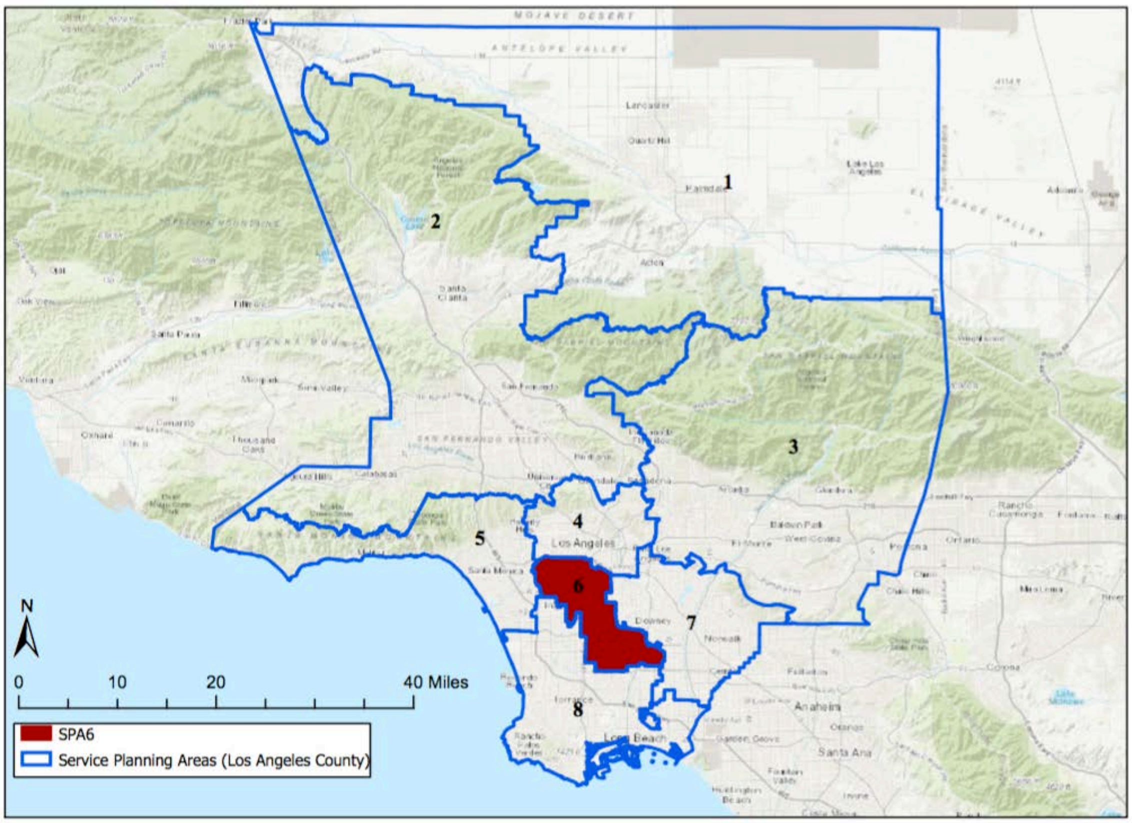

Figure 2. Service Planning Areas of Los Angeles County

SPA6 faces a wide variety of disadvantages in terms of social and economic resources, including insufficient affordable primary care provision and access. According to the 2016 American Community Survey, SPA6 has the largest proportion of low-income population of the eight SPAs of Los Angeles County. As indicated in the map on the left in Figure 3, 40% of residents in SPA6 live in households with an annual income lower than $35,000, whereas in SPA5, to the west, only 23% of residents live in such households. SPA6's economic disadvantage remains when using an even stricter definition of low-income population, as presented in the map on the right in Figure 3 below. More than 30% of the residents in SPA6 live in households with annual income lower than $25,000. The surfeit of individual economic resources seen in SPA6 must be taken into consideration when conducting a site suitability analysis for a new affordable primary care facility that serves SPA6 residents.

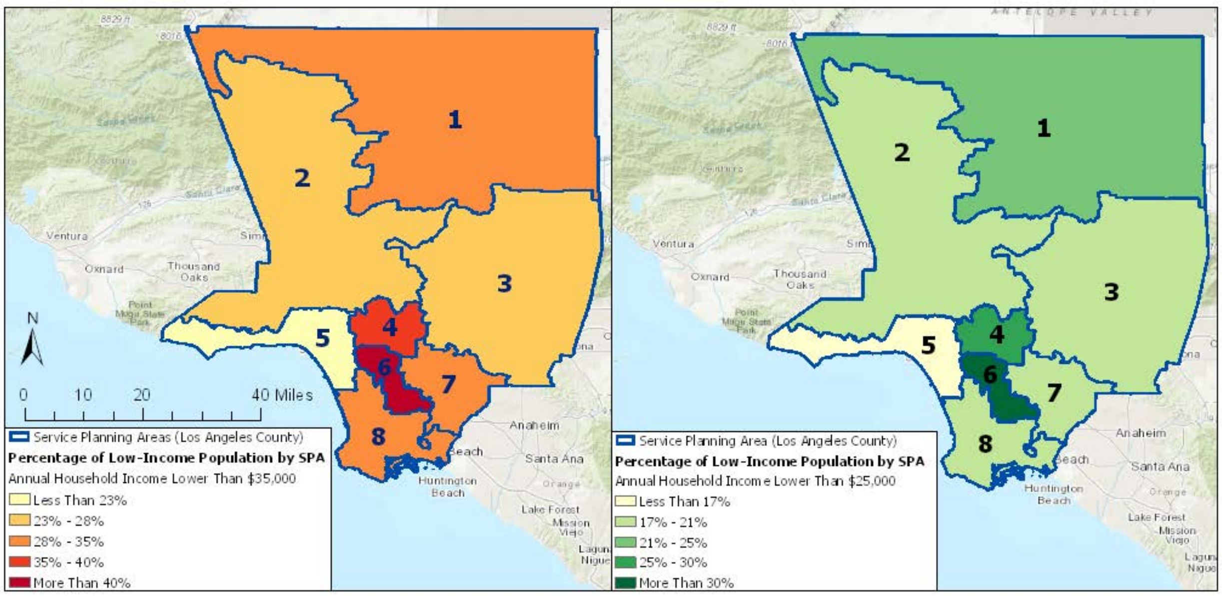

Figure 3. Low-Income Population by Service Planning Area

SPA6 features the lowest level of primary care provision amongst all eight SPAs, according to Los Angeles Department of Health Services. The four maps in Figure 4 present the status of overall primary care provision and low-cost primary care provision in Los Angeles County. The map on the top left depicts overall primary care provision normalized by population in each SPA. This reveals SPA6 has the lowest level of overall primary care provision in Los Angeles County. The map on the top right shows overall primary care provision normalized by low-income population whose annual household income is lower than $25,000. As shown in this map, SPA6's low-income population has the lowest level of primary care provision. Similarly, the map on the bottom left indicates the low-income population whose annual household income is lower than $35,000 also has the lowest level of primary care provision. The map on the bottom left corner shows affordable primary care provision normalized by low-income population, which reveals SPA6 is also among the areas with the lowest level of affordable primary care provision. Therefore, it is crucial to find a way to better provide affordable primary care in SPA6 to ensure SPA6's residents' right to medical care.

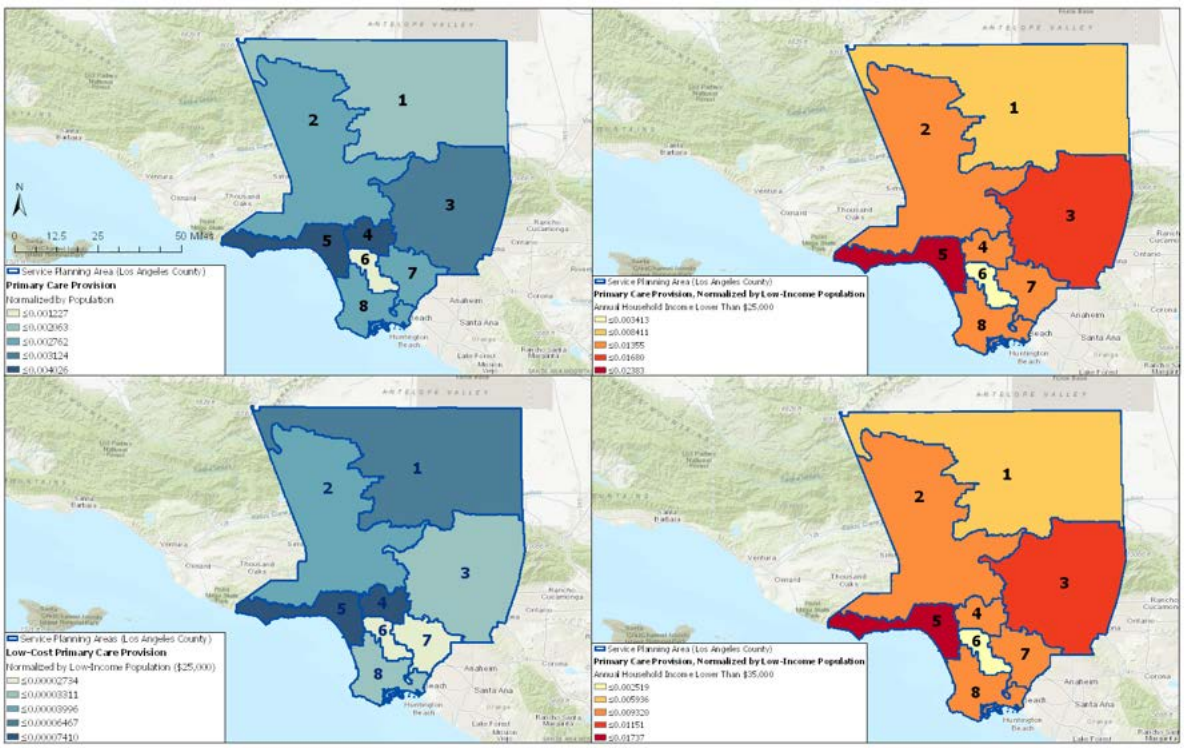

Figure 4. Primary Care and Low-cost Primary Care Provision by Service Planning Area

1.2. Research Question

The primary objective of this thesis is to identify a suitable site for a new primary care facility in SPA6. In order to best promote low-cost primary care accessibility in SPA6 with new primary care facilities, it is important to select sites that maximize the improvement of affordable primary care accessibility with the available resources. This project achieves this goal by first identifying suitable parcels in SPA6 and second measuring how much each candidate site would improve health care accessibility using the 2SFCA method.

This thesis has a two-fold spatial question:

1) What are the parcels in SPA6 that could potentially be a suitable and convenient site for a new low-cost primary care facility? and

2) Which of these parcels could increase the accessibility to affordable primary care for communities in SPA6 the most?

1.3. Structure of Thesis

This thesis consists of five chapters. Following this introductory chapter, Chapter 2 reviews related literature on primary care site selection and analytical methods for similar research topics. Chapter 3 introduces data sources and explains the methodology for this thesis project. Chapter 4 presents and discusses the results from the analyses described in Chapter 3. Chapter 5 concludes this thesis with a summary of results and a discussion of research limitations and future research.

Chapter 2 Literature Review

Inequities in primary care access are often severe for less-privileged individuals who neither have medical insurance nor the financial resources to afford health care. To provide a scholarly foundation for selecting a suitable site for a new affordable primary care facility to serve SPA6, this chapter reviews prior research on primary care, primary care facility site selection, and primary care accessibility.

2.1. Primary Care

In the health care system, four categories differentiate levels of care: 1) primary care provides the essentials of health care as well as coordinates patients with other levels of care; 2) secondary care is mostly provided by specialists for conditions that require a higher level of expertise than what primary care providers can offer; 3) tertiary care provides highly specialized health care for patients who need hospitalization; and 4) quaternary care is essentially an extension of tertiary care with unusual and even more highly specialized care (Torrey 2015). Among these four levels of care, primary care is particularly important because of it includes the most commonly used and comprehensive health care services. The social welfare and public health services covered within the rubric of primary care are crucial to broad-scale health outcomes. Moreover, access to primary care is particularly important for the underprivileged populations as poverty and undesirable health outcome tend to have a positive correlation (Hales et al. 1999). The remainder of this section discusses primary care in greater detail and analyzes the impacts of primary care provision on low-income populations

2.1.1. Primary Care

Primary care serves as a patient's entry point into the health care system. Primary care should coordinate health care services for patients and provide them long-term and comprehensive care while taking in consideration their societal context (Macinko et al. 2003). Furthermore, primary care combines curative and day-to-day preventive care. Overall, evidence shows that primary care improves individual and population health and is crucial in the health care system (Macinko et al. 2003).

The importance of primary care is two-fold. First, primary care is crucial for individual health. Donaldson et al. (1996) identify five benefits of primary for individual health outcomes: Primary care 1) treats or resolves a wide range of health problems so that patients can avoid needing higher level care; 2) guides patients through the health care system; 3) facilitates patient participation in decision-making regarding their own care; 4) prevents worse health outcome for the patients through health promotion and early detection of health problems; and 5) incorporates the patient with his/her family and community to achieve better health outcomes.

Second, primary care contributes to society in general by increasing the efficiency of health care through reducing preventable hospitalizations and by improving public health conditions (Donaldson et al. 1996). Preventable hospitalizations are those cases where outpatient care such as primary care can potentially prevent the need for hospitalization or prevent further complications and more severe medical conditions (Pezzin et al. 2018). Numerous studies identify a strong negative association between primary care provision and preventable hospitalizations; Namely, the number of preventable hospitalizations in a community is lower when there is higher primary care provision and vice versa (Parchman and Culler 1994; Bindman et al. 1995; Starfield 1995; Donaldson 1996). This relationship is especially true for conditions such as asthma, hypertension, congestive heart failure, chronic obstructive pulmonary diseases, and diabetes. In 1982, Medi-Cal benefits were terminated for 270,000 indigent residents of California. A number of researchers saw that this deprivation of primary care service created an opportunity to assess the relationship between access to primary care and health outcomes. Lurie and coauthors (1984, 1986) studied those who lost access to primary care and found their average health status worsened. Two decades later, Bindman et al. (2005) linked primary care required by Medicaid and lower hospitalization rates in California. Furthermore, primary care improves the cost efficiency of health care (Bindman et al. 2005). Adequate primary care not only improves the efficiency of health care by reducing preventable hospitalizations and the high cost associated with it (Bindman et al. 2005), but also saves costly specialized care by preventing or resolving a wide variety of health problems at early stages (Friedberg, Hussey, and Schneider 2010).

2.1.2. Primary Care and Low-Income Populations

In addition to the overall societal benefits discussed in the previous section, primary care is particularly important for the low-income population for two reasons. Firstly, low-income populations are more prone to health issues than populations with more financial resources. This is due to a wide range of reasons, such as limited access to healthy food and the lack of health information. Secondly, access to primary care for the low-income population can significantly mitigate the disadvantages caused by lack of financial resources. These two reasons are explored in the remainder of this section.

Researchers find strong evidence that supports the link between poverty and undesirable health outcomes across the world. Poverty is highly associated with infant mortality, a key indicator of public health. Hales and coauthors (1999) identify a negative relationship between national infant mortality rates and gross national product. Macinko and coauthors (2004) establish the same relation with empirical data from member countries of the Organization for Economic Cooperation and Development. Shi and coauthors (1999) find a similar negative correlation between state-level infant mortality rates and economic inequality using empirical data from the United States. Poverty is also linked to shorter life expectancy. DeVogli (2005) confirms this link with evidence from Italy. Marmot and Bobak (2000) use multi-national data to show this link both on the national and subnational levels. Poverty is also correlated with a series of undesirable health outcomes. Shi and coauthors (1999) show that citizens who live under the poverty line in the United States are more likely to suffer from several public health indicator diseases such as arthritis, cancer, cardiovascular diseases, diabetes, obesity, etc. Pickett and coauthors (2005) find similarly positive correlations between poverty and obesity in a cross-national study among industrialized countries. These research findings indicate that low-income populations tend to suffer more from health issues.

Scholars also demonstrate the causal relationship between sufficient primary care provision and better health outcomes among the low-income population. Using data from 26 health service areas in Pennsylvania, Parchman and Culler (1994) argue that preventable hospitalizations are significantly fewer where there is sufficient primary care provision and access even after controlling for socioeconomic status. Moreover, Casanova and Starfield (1995) provide evidence in a cross-national comparative study between Spain and the United States that a variation in the preventable hospitalization rate disappears once universal primary care access for children is introduced. Sood and coauthors (2014) examine the effects of a government insurance program in India that provides free health care access to citizens below the poverty line in half of the villages in the state of Karnataka. Since the villages receiving free health care access are randomly selected, the authors take this opportunity and design a quasi-experiment where the villages implementing the new government insurance program are the treatment group and the other half of the villages in Karnataka are the control group. They find that the average health outcomes are significantly better in the treatment group than the control group, demonstrating the causal relationship between increased health care access and more desirable health outcomes for low-income citizens.

Primary care has also been shown to reduce the cost of health care at the individual and societal levels (Donaldson 1996). First, primary care providers on average are less expensive than specialized care providers and other higher-level care providers (Donaldson 1996). Second, as discussed previously in this section, access to primary care significantly decreases the need for specialized care and hospitalization, which are considerably more expensive (Donaldson 1996). Improving access to primary care not only reduces the financial burden of health care for the low-income population, but also saves government health care expenditures by reducing avoidable high-level care and increasing health care efficiency. Dor and Holahan (1990) demonstrate that total Medicare expenditures per beneficiary decreases by one percentage point per ten percentage points increase in primary care provision. Moreover, geographical variation in primary care access also affects macro health care expenditures. Mark et al. (1996) and Welch et al. (1993) respectively demonstrate that increased primary care reduces overall Medicare expenditures and that insufficient primary care increases overall Medicare expenditures by examining local primary care provision in the United States.

In sum, improving access to primary care for a low-income population greatly benefits both the low-income population and the society as a whole. Primary care contributes to improving the health outcome of low-income communities and overall public health as well as to reducing the financial burden for both indigent individuals and the society. As the SPA with the highest percentage of low-income residents and the lowest level of primary care provision in Los Angeles County, SPA6 and its residents could benefit from additional primary care provision in terms of both economic conditions and health outcomes.

2.2. Site Selection for Primary Care Facilities

Site selection traditionally consists of two steps: The first step generates a small number of candidate sites by applying the predefined selection criteria, and the second step evaluates the resulting shortlist of candidate sites to identify the most suitable one (Chang et al. 2008). This section focuses on reviewing the site selection methods and criteria adopted in prior research. The rest of this section reviews the site selection criteria for health care facilities in previous research and the two commonly used methods for site selection – weighted overlay and fuzzy overlay.

2.2.1. Site Selection Criteria for Health Care Facilities

Selecting a suitable site is important for any new facility, because the facility in question could only function as intended if the site meets its needs. GIS provides powerful tools to analyze the needs of the facility and the attributes of candidate sites. Previous research conducted by both medical authorities and researchers using GIS has proposed a wide range of site selection criteria for health care facilities of different sizes and purposes. This section reviews the general site selection criteria applicable for most health care facilities including primary care facilities suggested in prior research.

2.2.1.1. Initial Filtering Criteria

Complex site selection analysis often requires an initial filtering step in order to increase computational efficiency (Estill & Associates 2006). For health care site selection analyses, three initial filtering criteria – consistency with zoning regulations, vacancy status, and parcel size – are frequently used to reduce the number of candidate sites (i.e. Estill & Associates 2006, Soltani and Marandi 2011, University of California San Francisco 2011).

Firstly, candidate sites for new primary care facilities should comply with zoning regulations (University of California San Francisco 2011). Specifically, a desirable candidate site should be a parcel with a zoning code that allows medical practices according to local zoning regulations. This criterion contributes to the computational efficiency of the site selection analysis by filtering out a large number of candidate sites with zoning codes inappropriate for a health care facility. Moreover, this criterion ensures the feasibility of the final site selection in the real world. According to the regulations and policies of Los Angeles County Department of Regional Planning, suitable zoning for a low-cost primary care facility falls in the commercial zoning category. Within the commercial zoning category, there are eight zoning codes: C-1, C-2, C-3, C-H, C-M, C-R, C-RU, and CPD. Table 2 below summarizes the requirements for each commercial zoning code with a focus on requirements for medical facilities.

Table 2. Summary of Zoning Regulations

Zoning	Permitted Uses	Minimum Required Area	Minimum Required Parking	Maximum Lot Coverage	Outside Storage
C-1	Zone C-H uses, commercial services, retail sales of new goods and genuine antiques	No minimum required area	1 parking space for each 250 sq. ft. of floor space for medical offices	90% of net area of lot	Not permitted
C-2	Zone C-1 uses, rentals, outdoor advertising, tailor shops	No minimum required area	1 parking space for each 250 sq. ft. of floor space for medical offices	90% of net area of lot	Not permitted

Zoning	Permitted Uses	Minimum Required Area	Minimum Required Parking	Maximum Lot Coverage	Outside Storage
C-3	Zone C-2 uses, secondhand stores	No minimum required area	1 parking space for each 250 sq. ft. of floor space for medical offices	90% of net area of lot	Permitted at the rear of a parcel when incidental to the permitted use in the front of the parcel
C-H	Community and financial services, parks and playgrounds, business and professional offices, no retail sales	No minimum required area	1 parking space for each 250 sq. ft. of floor space for medical offices	90% of net area of lot	Not permitted
C-M	Zone-3 uses, limited manufacture and assembly	No minimum required area	1 parking space for each 250 sq. ft. of floor space for medical offices	90% of net area of lot	Permitted at the rear of a parcel when incidental to the permitted use in the front of the parcel
C-R	Amusement parks, campgrounds, tennis courts, golf courses, limited agriculture	5 acres	N/A	No Maximum coverage	N/A
C-RU	Limited, low-intensity commercial uses that are compatible with rural and agricultural activities	N/A	N/A	50%	N/A
CPD	Single-family residences, crops, non-residential C-1 uses	5000 sq. ft.	1 parking space for each 250 sq. ft. of floor space for medical offices	40%	N/A

Source: Los Angeles County Department of Regional Planning

Secondly, candidate sites for new primary care facilities should be vacant to ensure the availability for construction (Estill & Associates 2006, Soltani and Marandi 2011). This criterion also contributes to the computational efficiency of the site selection analysis by eliminating unavailable candidate sites and the real-world accuracy by ensuring the final selected site is available for the new primary care facility.

Thirdly, candidate sites should be suitably sized (Estill & Associates 2006). Parcels that do not meet the basic spatial needs for parking and building of primary care facilities are too small, while parcels that exceed the spatial needs for primary care facilities are likely to result in waste in financial resources. Since all parcels with suitable zoning codes allow multiple-story buildings, previous research tends to analyze the size of candidate sites without considering the height of the facilities. Basic primary care facilities with one physician typically contain two to three exam rooms, a consultation room, and a reception room, which together require at least 1,200 square feet (Freedman 2007). Freedman (2007) suggests a method to estimate the size of a medical facility based on the number of physicians: 1,200-1,500 square feet for the first physician and 1,000-1,200 square feet for each additional physician. In order to catch as many otherwise suitable parcels as possible, this project defines the lower cutoff point for floor space based on the space required by the most basic one-physician facility: 1,200 square feet. Los Angeles County zoning regulations require one parking space per 250 square feet of floor space. According to the Transportation Engineering Online Lab Manual (2003), one parking space requires 310-330 square feet in the United States, including the driveway to access the parking space. This project takes the lowest required space, 310 square feet, to calculate the minimum space for the parking lot. Using this metric, the most basic primary care facility with one physician and 1,200 square feet of floor space will require five parking spots, which requires an additional 1,550 square feet, making the total minimum parcel size 2,750 square feet.

Unlike the minimum parcel size, the cutoff for parcels too large for a new low-cost facility is defined relatively flexibly because it is possible to have large-scale medical facilities and because a larger parcel size can allow for future expansion (Soltani and Marandi 2011). Los Angeles County Department of Health Services data shows that the number of physicians at existing low-cost primary care facilities ranges from zero (nurse practitioner or physician assistant-led facilities) to 45. The largest existing low-cost primary care facility in Los Angeles County, the LAC + USC Medical Center occupies a parcel of over 100,000 square feet. However, the LAC + USC Medical Center also provides secondary and tertiary care in addition to primary care. The largest parcel containing a facility that only provides low-cost primary care is around 25,000 square feet.

2.2.1.2. Key Site Selection Criteria

Prior research on site selection for health care facilities suggests four key site selection criteria including proximity to public transit, distance to existing similar facilities, land cost, and proximity to targeted service recipients.

Firstly, as a facility that provides primary care services to the public, a primary care facility should be close to public transit (Soltani and Marandi 2011). Proximity to the public transit system is particularly important for health care facilities intended for disadvantaged groups such as elderly or low-income residents as they might not have access to private vehicles (Wu et al. 2007). Prior studies often employ proximity to public transit stops as a measurement of this criteria (Soltani and Marandi 2011), namely, the closer a candidate site is to the nearest public transit stop, the more desirable it is.

Secondly, a new health care facility should not be in the close vicinity of an existing health care that provides similar services to avoid the waste of resources due to overlapping service provision (Estill & Associates 2006, Soltani and Marandi 2011). There are two common ways to measure the distance from a candidate site to existing health care facilities that provide similar services. The first way defines the distance from a candidate site to existing health care facilities that provide similar services in a binary way where candidate sites within a certain distance of any existing similar facilities are considered unqualified while other candidate sites remain in the candidate pool (Estill & Associates 2006). While this method is convenient and easy to compute, the binary separation of suitable and unsuitable candidate sites might exclude potentially satisfactory sites that are right outside the pre-defined distance. The second way measures this criterion with the actual distance from a candidate site to existing health care facilities that provide similar services (Soltani and Marandi 2011). This method provides a more accurate measurement for this criterion but increases analytical complexity for the site selection analysis.

Thirdly, land cost is a criterion for primary care facility site selection. This criterion is important because land cost can potentially vary significantly while most of the other costs related to a new primary care facility are relatively fixed (Vahidnia, Alesheikh, and Alimohammadi 2008). For instance, for a primary care facility that has three physicians, two nurse practitioners, five registered nurses, and five exam rooms, the labor cost, site construction cost, medical service cost, and operational cost are relatively stable regardless of the location of the new facility in a given neighborhood, city, or county. However, land cost can vary considerably across a study area, especially in and around a metropolitan area such as Los Angeles. Therefore, evaluating land cost for candidate sites is crucial if one wants to select the cheapest suitable site for a new primary care facility. The most financially efficient way to use a fixed amount of financial resources on a new primary care facility that aims at increasing primary care provision is to choose sites with lower land cost, all else being equal. The less money spent on site purchase, the more money there will be for primary care provision.

Lastly, proximity to targeted service recipients is one of the most common criteria for health care facility site selection (Schuurman et al. 2006). Ideally, a health care facility should be close to as many potential clients as possible. There are two aspects to this assessment: first the population of potential clients must be identified, and second, the proximity must be measured. Population density and local socio-demographics are usually used as proxies to measure the number of potential clients close to the facility. For general health care facilities such as primary care providers, population density alone constitutes a regularly used criterion since everyone can be a potential recipient of their service (e.g. Schuurman et al. 2006; Wu, Lin, and Chen 2007 ; Vahidnia, Alesheikh, and Alimohammadi 2008). A site in an area with a larger population is more suitable for a primary care facility intended for the general public, *ceteris paribus*. Similarly, an ideal site for a primary care facility that focuses on a specific group of potential clients should take into consideration its socio-demographic characteristics. For instance, a clinic that aims at providing health care to elderly residents should consider the population of adults over 65 years of age (Kim et al. 2015). Therefore, this thesis includes the size of low-income populations within one mile of candidate sites as one of the site selection criteria.

2.2.2. Weighted Overlay and Fuzzy Overlay

The previous section discusses key criteria for selecting suitable sites for primary care facilities and this section reviews methods commonly used to integrate these criteria in the site suitability analysis. Weighted overlay and fuzzy overlay are two commonly used methods to rate suitable locations in site suitability analyses (Mitchell 2012).

In weighted overlay, analysts bring together data layers of their chosen criteria and weight them relative to each other in terms of their impact on suitability. For instance, if a site suitability analysis includes three criteria – land cost, slope, and aspect – analysts would first gather data and create a source layer for each of these three criteria. Second, analysts must create classes within each source layer and assign values to those classes using a scale of their own choosing. Higher values are given to those classes that are more suitable. For instance, if analysts are using land cost as a factor and want to keep land costs down, they will break up parcels into classes based on cost and assign higher values to those parcels with lower land costs. Third, analysts assign weights to each data layer according to its relative importance in the overall analysis: the criteria that are deemed more important to the outcome are given higher weights. Finally, analysts overlay the layers by adding up the weighted values of all the suitability criteria for each location.

The fuzzy overlay method provides a tool for site suitability analyses where site selection criteria are defined by continuous data without clear cut-off points between suitable values (Mitchell 2012). Similar to the weighted overlay method, the fuzzy overlay method requires analysts to first define a set of criteria for the site selection and create corresponding data layers for further analysis.

Instead of assigning values on a scale of their own choosing to the observed data, the fuzzy overlay method requires analysts to reclassify the observed data to values on a common continuous scale of zero to one which represent the probability of candidate sites belonging to sets of site selection criteria (Baidya et al. 2014). This value is called the fuzzy membership value. A fuzzy membership value of zero indicates non-membership and a fuzzy membership of one indicates full membership (Mitchell 2012). This contrasts from values in a weighted overlay analysis, in which higher values represent more favorable sites. Furthermore, the fuzzy overlay method allows analysts to transform observed data to fuzzy membership values with different functions, giving the method more analytical flexibility. For instance, the Fuzzy Gaussian function transforms observed data into a normal distribution, the Fuzzy Large function transforms the observed data in a way so that larger input values are more likely to be a member of the set, and the Fuzzy Near function transforms observed data by assigning full membership to the midpoint data and decreasing the fuzzy membership value as values move away from the midpoint data (Esri 2018a).

The fuzzy overlay method provides a variety of ways to assess the fuzzy membership values for each data layer against each other, again providing more analytical flexibility than the weighted overlay method, which only employs addition of values. Esri's GIS products allow two different logical and three different mathematical fuzzy overlay methods. The Fuzzy And overlay type returns the minimum value of all input fuzzy membership values at each cell and the Fuzzy Or overlay type returns the maximum value (Esri 2018b). Among the three mathematical overlay types in the fuzzy overlay method, the Fuzzy Product overlay type multiplies all input fuzzy membership values at each cell, the Fuzzy Sum overlay type sums all input fuzzy membership values at each cell, and the Fuzzy Gamma overlay type combines the Fuzzy Product and Fuzzy Sum overlay types by raising both to the power of gamma (Esri 2018b).

These two site selection methods each have their own advantages and disadvantages for different site suitability analyses. The weighted overlay method is convenient and intuitive but it requires well-defined, quantifiable criteria and lacks computational flexibility when combining different criteria. The fuzzy overlay method is more flexible in terms of data requirements and methods to combine different criteria even though it tends to be more complicated. As Mitchell (2012) argues, the weighted overlay method is desirable for rating suitable locations when the site selection criteria are defined by distinct categories or class ranges with clear cut-off points.

The fuzzy overlay method, in contrast, is desirable when criteria are defined by continuous data with no clear cut-off points between suitable and unsuitable sites (Mitchell 2012). For instance, the weighted overlay method is desirable when the analyst clearly knows candidate sites that cost lower than $300 dollars per square foot are suitable. But the fuzzy overlay method is more preferable than the weighted overlay method when the analyst only has a general idea that cheaper sites are more suitable. In addition, the weighted overlay method is ideal when the relationship between the overall suitability of a site and site selection criteria is linear while the fuzzy overlay method is suitable when the relationship is more complicated. If the suitability level of candidate sites is not only related to the weighted sum of all site selection criteria, the weighted overlay method is likely to be inappropriate. Consider the selection of a suitable site for a giant panda reserve as an example. The three criteria are coverage of bamboos, site size above 10,000 hectares, and access to fresh water. Among the three criteria, coverage of bamboos is a necessary condition. If an analyst adopts the weighted overlay method for this site suitability analysis, there is a chance that a site with no coverage of bamboos but extremely high ratings on the other two criteria would be considered as suitable. Therefore, in this case, the weighted overlay method is not appropriate.

2.3. Evaluating Accessibility

After reviewing methods and criteria for the first stage of site selection in the previous section, this section focuses on research related to the second stage, namely, the evaluation stage. Since the goal of this project is to identify a suitable site for a new low-cost primary care facility in order to increase the primary care accessibility of low-income residents in SPA6, the evaluation stage is centered on accessibility. Therefore, this section reviews methods to evaluate and measure accessibility.

2.3.1. Earlier Methods to Measure Accessibility

One of the most commonly used conventional methods to measure accessibility is the provider-to-population ratios (Guagliardo 2004). This method is intuitive and easy to compute: analysts simply have to define areal units and divide the number of health care providers by the number of residents within a given areal unit. The provider-to-population ratio is suitable for comparisons of health care supply between large geopolitical units such as states and countries (Connor, Hillson, and Krawelski 1995; Fortney et al. 1995). However, this method is problematic because it does not account for a variety of issues that undermine the stability of values across and between the chosen areal units such as patient border crossing, variation in accessibility within areal units, or travel impedance (Guagliardo 2004). Thus, it suffers from what is known as the modifiable areal unit problem (MAUP). Since this thesis aims to evaluate primary care accessibility of SPA6, a relatively small geographical area bordering other urban areas, the provider-to-population ratio method is not suitable.

Building on the concept of provider-to-population ratios while striving to address the MAUP, gravity models provide more valid measures of spatial accessibility (Guagliardo 2004). Gravity models aim to reflect the potential interactions between all population points and all provider points within a certain distance while accounting for travel impedance. Instead of calculating one provider-to-population ratio for each areal unit, gravity models account for all potential providers for a given population point. Moreover, Guagliardo (2004) introduces the concept of health care service capacity to represent the supply of primary care and uses the number of physicians as the indicator for health care service capacity. The basic form of gravity models can be summarized in the formula below:

$$A_i = \sum_j \frac{S_j}{d_{ij}^{\beta}}$$

where accessibility (*A*) for population (*i)* is the sum for all provider locations (*j*) of the ratio of service capacity *S* at provider location *j* to the travel impedance *d* between *i* and *j*, modified by the gravity decay coefficient β. Travel impedance can be either travel distance or travel time. Gravity models successfully account for the MAUP, yet, the results from gravity models tend to be less intuitive in comparison to the conventional physician-to-population ratio. More importantly, gravity models omit an important aspect of accessibility: the demand. Gravity models only use population in terms of a location point from which to measure travel impedance, such as the centroid of a census tract; The size of the population does not affect the accessibility results. For instance, according to the gravity model of accessibility, the primary care accessibility of a town with two primary care providers and 1,000 residents would be the same as an otherwise identical town 10,000 residents. This is problematic.

The method by which gravity models assess provision capacity – a simple count of the number of physicians – is also problematic. Firstly, using the number of physicians as the indicator for primary care provision capacity assumes all physicians provide the same amount of primary care, which is unrealistic. Even assuming each physician provides approximately the same amount of primary care per unit time, the working hours for physicians at different primary care facilities differ significantly. Secondly, using the number of physicians as the indicator for primary care provision capacity neglects the primary care provided by other medical professionals. Evidence from previous research shows that non-physician clinicians such as nurse practitioners and physician assistants can also provide primary care when they have their own panel of patients and supporting teams (Altschuler et al. 2012, Dill et al. 2013).

2.3.2. 2-Step Floating Catchment Area

The 2SFCA method builds upon conventional gravity models of accessibility by including a measurement of demand. First introduced by Luo (2004) as the floating catchment area (FCA), this method thus considers both the supply and the demand of a resource. Moreover, it also provides a flexible way to assess primary care accessibility that is not constricted by the MAUP and border effects.

Using the FCA method (Luo 2004), analysts first construct catchment areas for the demand locations by defining the centers and radius. Population points, which can be a home address if data allows or the centroid of an areal unit of population such as a census tract, are the centers of catchment area. The radius of catchment areas is the distance that the user of a resource is willing or able to travel to access that resource. Secondly, analysts add population and provider data to each catchment areas and calculate the provider-to-population ratio. The result is the measurement of accessibility. For instance, in an FCA analysis where catchment areas are defined as circles centered on census tract centroids with a 5-mile radius, if the catchment area centered on the centroid of census tract *A* contains four other census tract centroids and three points representing service provider locations, the provider-to-population ratio for census tract *A* would be ratio of the total number of providers at the three provider locations and the sum of population in the five census tracts.

One limitation of the FCA method is that it neglects the possibility that providers at the periphery of a catchment could also provide service to potential patients in nearby catchments. Moreover, the FCA method assumes equal accessibility to all providers in a catchment for all potential patients in that catchment. In order to address these issues, Wang and Luo (2005) proposed the 2SFCA method.

The 2SFCA method, as its name indicates, consists of two steps: conducting the floating catchment area calculation once from provider points and again from population points. The first step calculates the provider-to-population ratios for the catchments centered on provider points. Analysts define the radius of catchments just as in the FCA method, but the 2SFCA method allows the radius to be measured as travel time via transportation networks in addition to simple Euclidean distance. Previous research using the 2SFCA method to determine primary care accessibility tends to define the radius of catchment areas by travel time via private vehicle. For instance, Lee (1991) proposes 30 minutes as a reasonable driving time for primary care in rural areas. Luo and Wang (2005) tests the 2SFCA method using driving time thresholds from 20 to 50 minutes. Travel time by private vehicle on a road network provides a more realistic measurement of spatial accessibility than Euclidean distance because it reflects the cost to access primary care facilities for potential clients. Moreover, road network datasets for travel time analysis have become widely available in the past decade. Therefore, most previous research research regarding 2SFCA uses travel time by private vehicle to calculate travel time. However, while travel time by private vehicle on a road network already provides a more desirable measurement than Euclidean distance, it still does not fully capture the travel cost for potential clients due to the underlying assumption that all potential clients have access to private vehicles. For instance, some potential clients, especially the low-income clients, may reply on public transit to access primary care services. Yet, few previous research projects consider travel time through public transit as a measurement of the catchment area radius due to the lack of road network datasets constructed for public transit.

After the catchments for each provider point are drawn, a provider-to-population ratio is calculated by dividing the total capacity of primary care provision by the total population within the catchment. Similar to the earlier accessibility measures such as the provider-to-population ratio and Floating Catchment Area methods, Wang and Luo (2005) also use the number of physicians as the indicator for primary care provision capacity. For instance, Figure 5 below provides an example area that consists of six rectangles to represent six census tracts: Census Tract 1 with 2,000 residents, Census Tract 2 with 3,000 residents, Census Tract 3 with 1,000 residents, Census Tract 4 with 1,500 residents, Census Tract 5 with 1,000 residents, Census Tract 6 with 1,000 residents. The small blue circles are the centroids of each census tract. In this example, they are also the population centers. The small blue triangles represent the primary care provider locations: Provider Location 1 with five physicians, Provider Location 2 with three physicians, and Provider Location 3 with four physicians. The three blue polygons are the catchment areas of the three provider locations based on travel time. The catchment area for Provider Location 1 includes the centroids of Census Tracts 1 and 4, and thus the provider-to-population ratio for Provider Location 1 is 5:(2,000 + 1,500), namely, 1:700. Similarly, the provider-to-population ratios for Provider Location 2 and 3 are 3:(1,000 + 1,000) and 4:(1,500 + 1,000 + 1,000), namely, 3:2000 and 1:875.

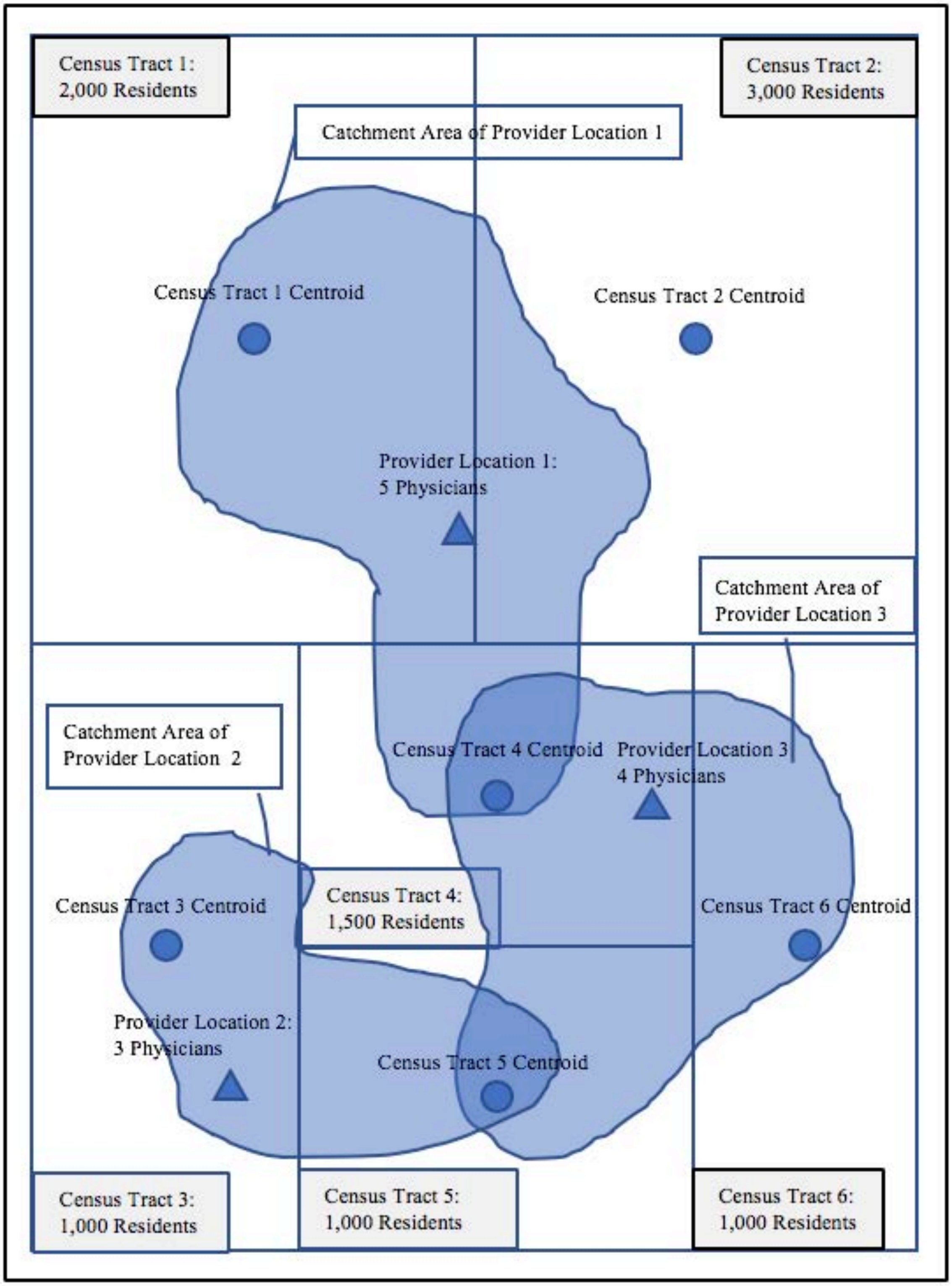

Figure 5. Illustration of the First Step in 2SFCA

The second step begins by drawing catchment areas for each population point. Next, the provider-to-population ratios for each provider location that within each population catchment are summed. For instance, if a given population point sits within the catchment areas of two provider location points, the provider-to-population ratios for those two provider location points are summed to generate the accessibility score for the population point. For instance, as shown in Figure 6, the red polygon is the catchment area for Census Tract 4. This catchment area contains two provider locations, namely, Provider Location 1 with a provider-to-population ratio of 1:700 and Provider Location 3 with a provider-to-population ratio of 1:875. Therefore, the accessibility score for Census Tract 4 is the sum of these two provider-to-population ratios, which is approximately 0.00257.

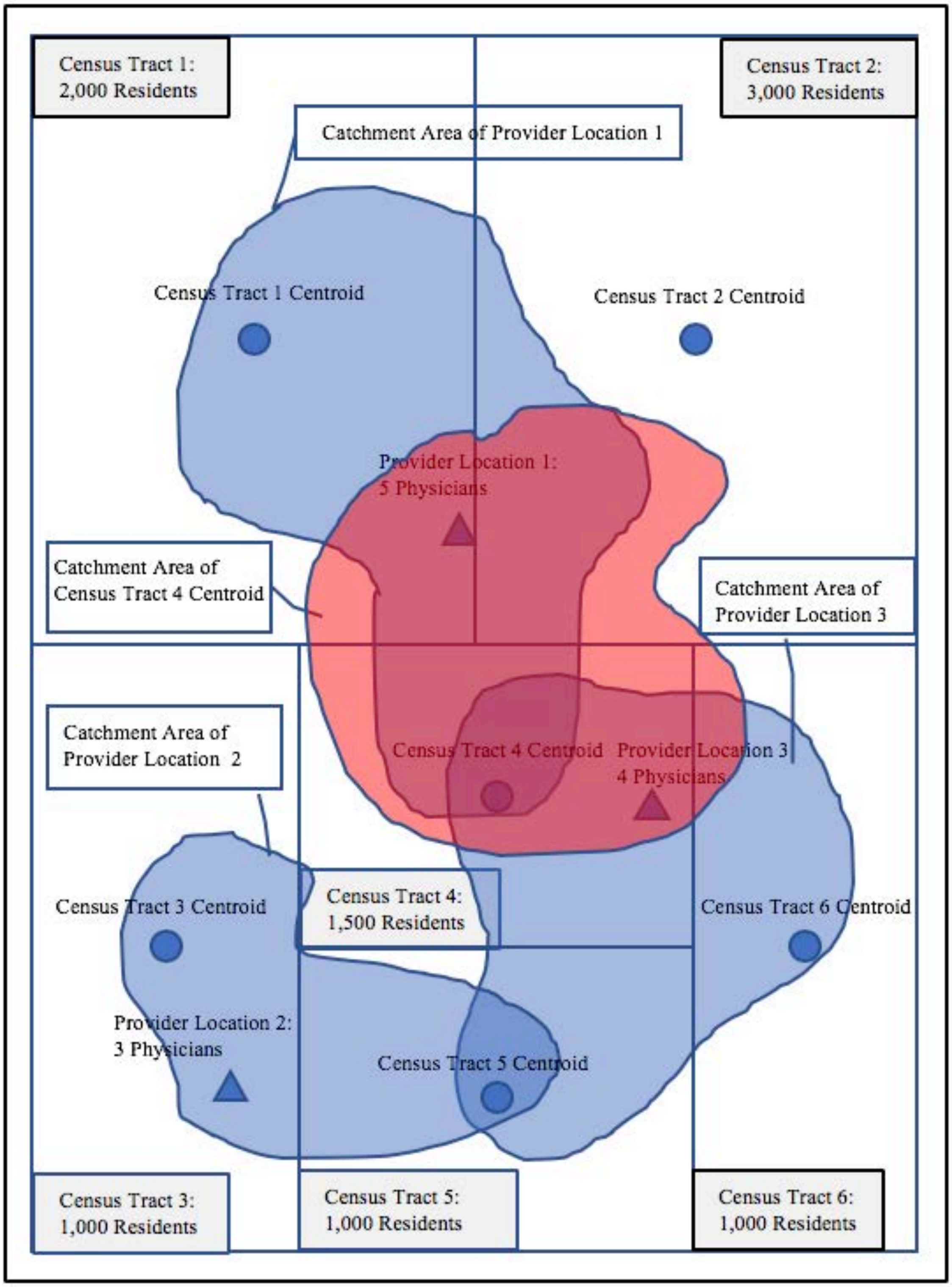

Figure 6. Illustration of the Second Step in 2SFCA

The two steps in 2SFCA discussed above can be summarized with the following two formulas:

$$R_j = \frac{S_j}{\sum_{k\in}\{d_{ij} \le d_0\}P_k}$$

$$A_i^F = \sum_{j\in\{d_{ij} \le d_0\}} R_j$$

For each provider point *j*, S_j is the service provision capacity, P_k is the population that falls into the catchment area of *j*, R_j is the provider-to-population ratio for point *j*, and d_{ij} is the travel time through road network between the provider location *j* and the population location *i* and d_0 is the cutoff travel time for the catchments. A_i^F is the accessibility score for location *i*, which is the sum of the provider-to-population ratios for each provider point *j* inside of the catchment area based on location *i*.

2.3.3. Public Transit in Measuring Accessibility

Paez, Scott, and Morency (2012) define accessibility as the potential for reaching spatially distributed opportunities. They measure this using the cost of travel and the quantity of opportunities. Previous accessibility research on health care facilities tends to measure the cost of travel with travel time or distance to service by private transport, which includes indicators such as the distance from a candidate site to major roads and driving time to a candidate site via a road network (i.e. Wu et al. 2007; Brabyn and Beere 2006). However, potential patients' ability to afford transportation could undermine primary care accessibility for low-income populations since their access to private vehicles might be limited. Martin et al. (2008) demonstrates that spatial access to health care services by public transport is significantly different from access by private transport, which raises the need to incorporate public transport accessibility into low-cost primary care facility site selection. Therefore, it is not sufficient to simply calculate travel time based on automobile in site selection for a low-cost primary care facility. The analysis should also consider travel time via public transit in order to more accurately measure geographical accessibility.

In prior research that considers the public transit factor, proximity to public transit stops is often used as a measurement of public transport accessibility (Soltani and Marandi 2011). However, this method does not account for travel time via public transit accurately or in detail. Martin et at. (2008) proposed to take advantage of public transit timetable data and used Microsoft Visual Basic to calculate travel time via public transit for the Derriford Hospital in Devon, England. While effective, Microsoft Visual Basic is more demanding in terms of coding in comparison to ArcGIS. The Add GTFS (General Transit Feed Specification) to a Network Dataset tool in ArcMap provides a powerful solution in network analysis to perform schedule-ware analysis, which is ideal for calculating travel time via public transit (Esri 2018c).

Chapter 3 Data and Methodology

The key goals of this project were to identify potential suitable sites for a new low-cost primary care facility in SPA6 of Los Angeles County and to evaluate those potential new sites for their ability to improve accessibility to primary health care for residents of SPA6. Chapter 2 reviews prior research on site selection and site evaluation for primary care facilities. Building upon this prior work, this chapter discusses the data and methods used in this thesis project.

This chapter discusses data used in this project and the data preparation process in the first section. This section first defines the study area for this thesis before introducing datasets used in this study, including existing low-cost primary care facilities, service planning areas, census tracts, demographic data, parcels and zoning information, public transit, and road network in SPA 6 and Los Angeles County.

The other two sections in this chapter focus on the methods adopted in this study. This project employed the fuzzy overlay and 2SFCA methods in two analytical stages: site selection and site evaluation. This project first generated a shortlist of candidate sites through the fuzzy overlay method. Instead of simply evaluating the suitability of the candidate sites with the fuzzy membership values like conventional site suitability analyses, this project employed the 2SFCA method, a novel quantitative measurement of accessibility, to evaluate how each candidate site on the shortlist affects the primary care accessibility for low-income populations in SPA6. In the site evaluation stage, this project calculated low-cost primary care accessibility scores for each low-income population point in SPA6 with existing low-cost primary care facilities as the baseline accessibility and then calculated the accessibility scores with the addition of each candidate site to compare with the baseline.

3.1. Data Sources and Data Preparation

This section introduces the data used in this thesis for the fuzzy overlay site selection analysis and the site evaluation analysis with 2SFCA. Table 3 below summarizes the data sources used in this thesis. The datasets for low-cost primary care facilities, SPAs, census tracts, demographics, zoning, parcel boundaries, and road network were downloaded directly from the sources. The dataset for the provision capacity of each low-cost primary care facility in Los Angeles County was constructed by the author for this project by combining data on the number of primary care providers and business hours at each existing low-income primary care facility from the Los Angeles County Department of Health Service and the websites of the low-cost primary care facilities. A public transit road network dataset was constructed by the author for this project using data from the United States EPA Smart Location Database on routes, stops, and schedules of public transit in Los Angeles County. The rest of this section discusses each data source in detail.

Table 3. Data Sources

Dataset	Source	File Type	Purpose
Service Planning Areas	Los Angeles County Department of Health Service	Vector Polygon Shapefile	Fuzzy Overlay; 2SFCA
Census Tracts	United States Census Bureau	Vector Polygon Shapefile	Fuzzy Overlay; 2SFCA
Demographics	American Community Survey by Census Bureau	Table	Fuzzy Overlay; 2SFCA
Parcels and Zoning	Los Angeles County GIS Portal	Vector Polygon Shapefile	Fuzzy Overlay
Low-Cost Primary Care Facilities	Los Angeles County Department of Health Services	Vector Point Shapefile	Fuzzy Overlay; 2SFCA
Low-cost Primary Care Provision Capacity	Los Angeles County Department of Health Service;	Table	2SFCA

	Websites of Low-cost Primary Care Facilities		
Public Transit	United States EPA Smart Location Database	Vector Point Shapefile	Fuzzy Overlay; 2SFCA
Los Angeles County Road Network	UCLA Geoportal	Vector Line Shapefile	Fuzzy Overlay; 2SFCA

3.1.1. SPA Boundaries

As introduced in Chapter 1, the study area of this thesis is SPA6 of Los Angeles County. This section further elucidates the geographical extent and spatial units of the analysis. The boundary data of SPA6 was acquired from the Los Angeles County Department of Health Services along with the boundaries of the other seven SPAs in the county.

In order to account for patients crossing SPA boundaries to seek primary care services and outside SPA6, this analysis employed a three-mile buffer around SPA6 as the extended study area. Figure 7 below shows both the SPA6 and the extended study area.

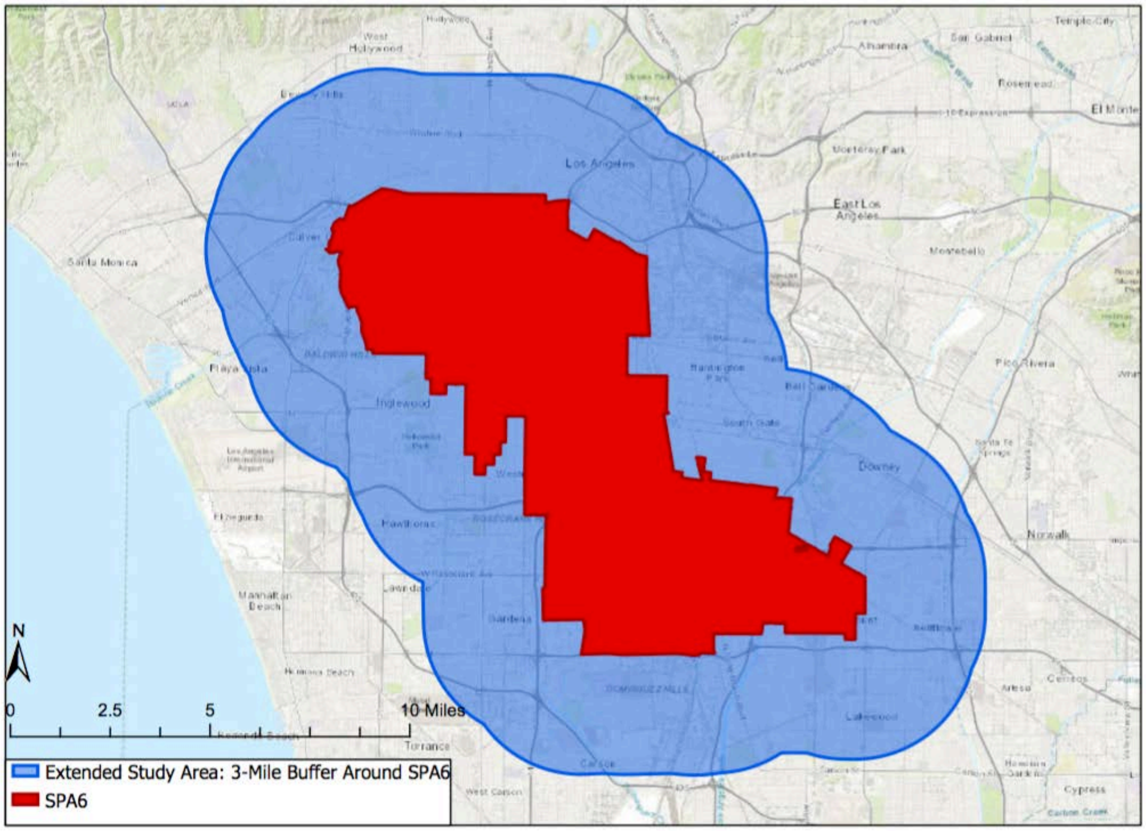

Figure 7. Extended Study Area

3.1.2. Low-Income Populations

The American Communities Survey offers data on demographic and income information by census tracts. The 2016 American Communities Survey was the most updated version with detailed data on the census tract level during the data collection phase of this project.

The U.S Census Bureau sets the poverty thresholds for households of specified sizes annually on the federal level. However, the federal poverty thresholds might not accurately reflect the poverty status in Los Angeles because they do not account for difference in the cost of living or government poverty relief programs across the country. Aiming to address this problem, the U.S. Census Bureau also provides the Supplemental Poverty Measure (SPM) as an alternative poverty threshold guideline. Table 4 below presents both the federal poverty thresholds and the SPM for the Los Angeles-Long Beach-Anaheim metropolitan area, where SPA6 is located. Since the demographic data acquired for this project is from the 2016 American Community Survey, this project also adopts poverty data in 2016.

Table 4. Federal Poverty Thresholds for Households of Specified Sizes

Poverty Guideline	Household Size							
	1	2	3	4	5	6	7	8
Federal	12,228	15,569	19,105	24,563	29,111	32,928	37,458	41,781
SPM for Renters	15,900	22,420	34,308	41,962	49,056	55,734	62,084	68,167
SPM for Homeowners with Mortgage	15,954	22,495	34,424	42,104	49,222	55,922	62,294	68,397
SPM for Homeowners without Mortgage	13,224	18,645	28,532	34,897	40,797	46,350	51,632	56,691

Data Source: U.S. Census Bureau

The average size of household in the United States is 2.58 according to the 2016 American Community Survey. Therefore, this project chose the threshold for low-income populations for this analysis between the SPM thresholds for households of two and three. As Table 4 indicates, the poverty guideline is $22,420 for households of two renters, $22,495 for households of two homeowners with mortgage, $18,645 for households of two homeowners without mortgage, $34,308 for households of three renters, $34,424 for households of three homeowners with mortgage, $28,532 for households of three homeowners without mortgage. It would be ideal if this project could calculate the poverty guideline for households of 2.58 people and use it to define low-income populations. However, the American Community Survey does not report household income as a ratio variable. Instead, it aggregates annual household income data into categories including less than $10,000, $10,000 - $15,000, $15,000 - $25,000, $25,000 - $ 35,000, and so on. Therefore, this project selected $25,000, a number between the SPMs for households of two and three that is also available in the American Community Survey, as the cutoff for low-income populations. Figure 8 below shows the number of low-income residents by census tract in the extended study area:

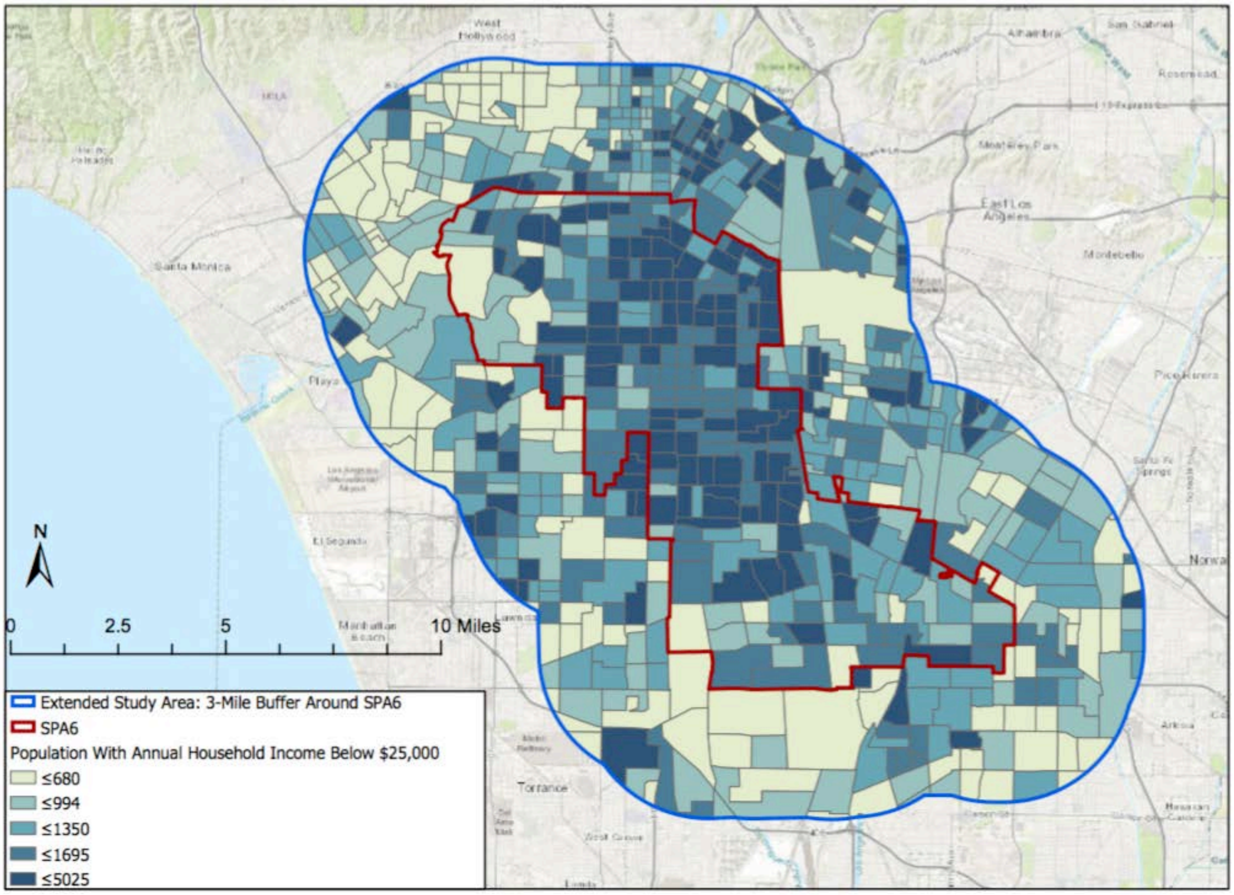

Figure 8. Low-Income Populations by Census Tract

3.1.3. Zoning and Parcel Dataset

In this thesis, parcel data in the extended study area is the candidate pool for site selection. This project acquired parcel data from the Los Angeles GIS Portal. The parcel dataset includes zoning information, parcel size, land value, address, and other attributes of the parcels.

This dataset provides information for three site selection criteria discussed in Chapter 2. Firstly, the parcel size data can be used to filter out parcels that are too big or too small for a new low-cost primary care facility. Secondly, the zoning data allows this analysis to select only parcels with commercial zoning that is proper for medical facilities. Thirdly, the land value data allows the fuzzy overlay analysis to use it as a factor. Figure 9 below presents the parcel data with zoning information in the extended study area:

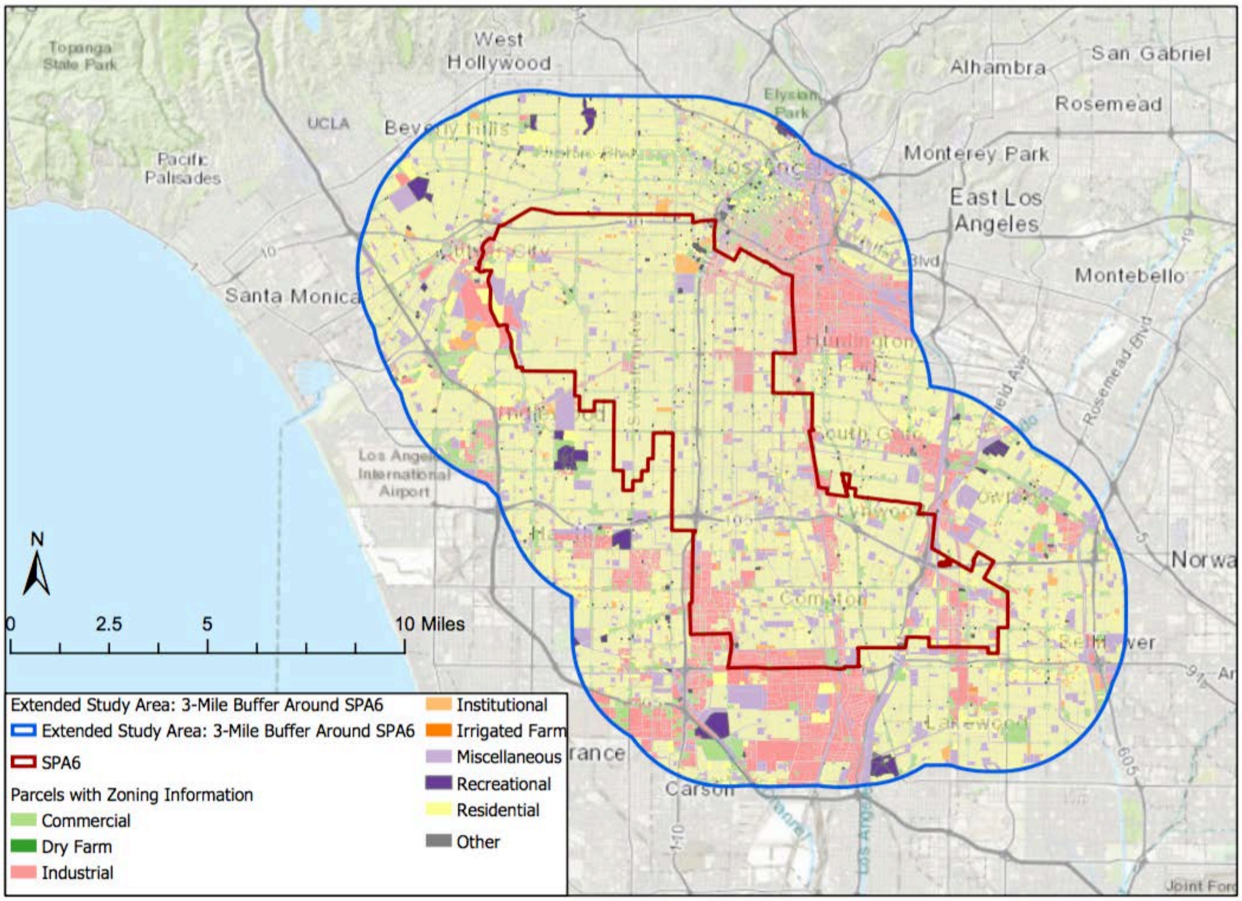

Figure 9. Parcel Data with Zoning Information

3.1.4. Public Transit Dataset and Road Network Dataset

As discussed in Chapter 2, public transit is a key factor both in the site selection for a new low-cost primary care facility that serves low-income populations and in the 2SFCA site evaluation. A desirable site should be easily accessed via public transit. Moreover, travel time via public transit is an important factor for defining catchment areas for the 2SFCA analysis that evaluates the impact on primary care accessibility brings by each candidate site.

This project acquired public transit data from the U.S. Environmental Protection Agency Smart Location Database. This dataset contains public transit routes, stops, 0.25 and 0.5-mile Euclidean buffers from public transit stops, number of trips per hour, and maximum wait time by time periods throughout the day. Figure 10 shows the public transit routes and stops:

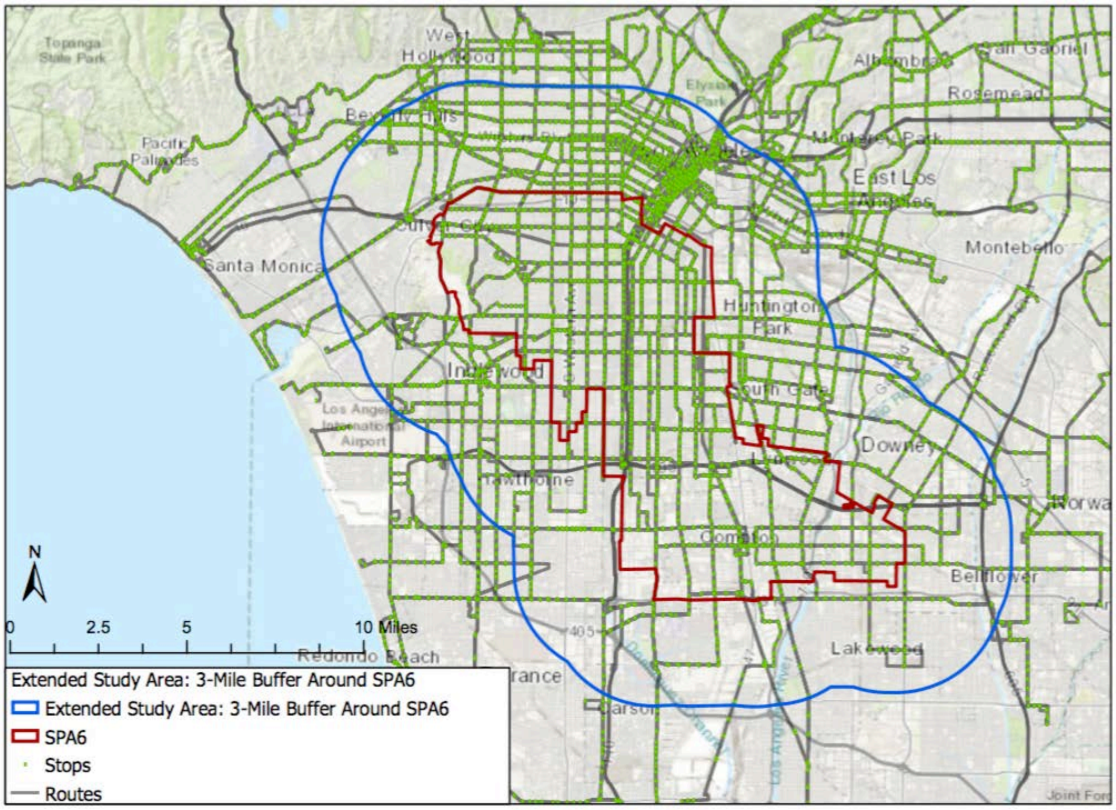

Figure 10. Public Transit Routes and Stops in the Extended Study Area

In order to define catchment areas in the 2SFCA analysis, this project needed to generate travel time for both private vehicles and public transit. Since road network datasets for public transit is not widely available, this project acquired public transit data such as bus routes, bus schedule, subway routes, and subway schedule from the U.S. EPA Smart Location Database in order to create a road network dataset for public transit. For the private vehicle travel-time calculation, this project acquired the road network dataset for Los Angeles County from the

UCLA Geoportal. This road network dataset was generated based on the street layer from Esri data and map collection. Figure 11 below shows the road network in the extended study area:

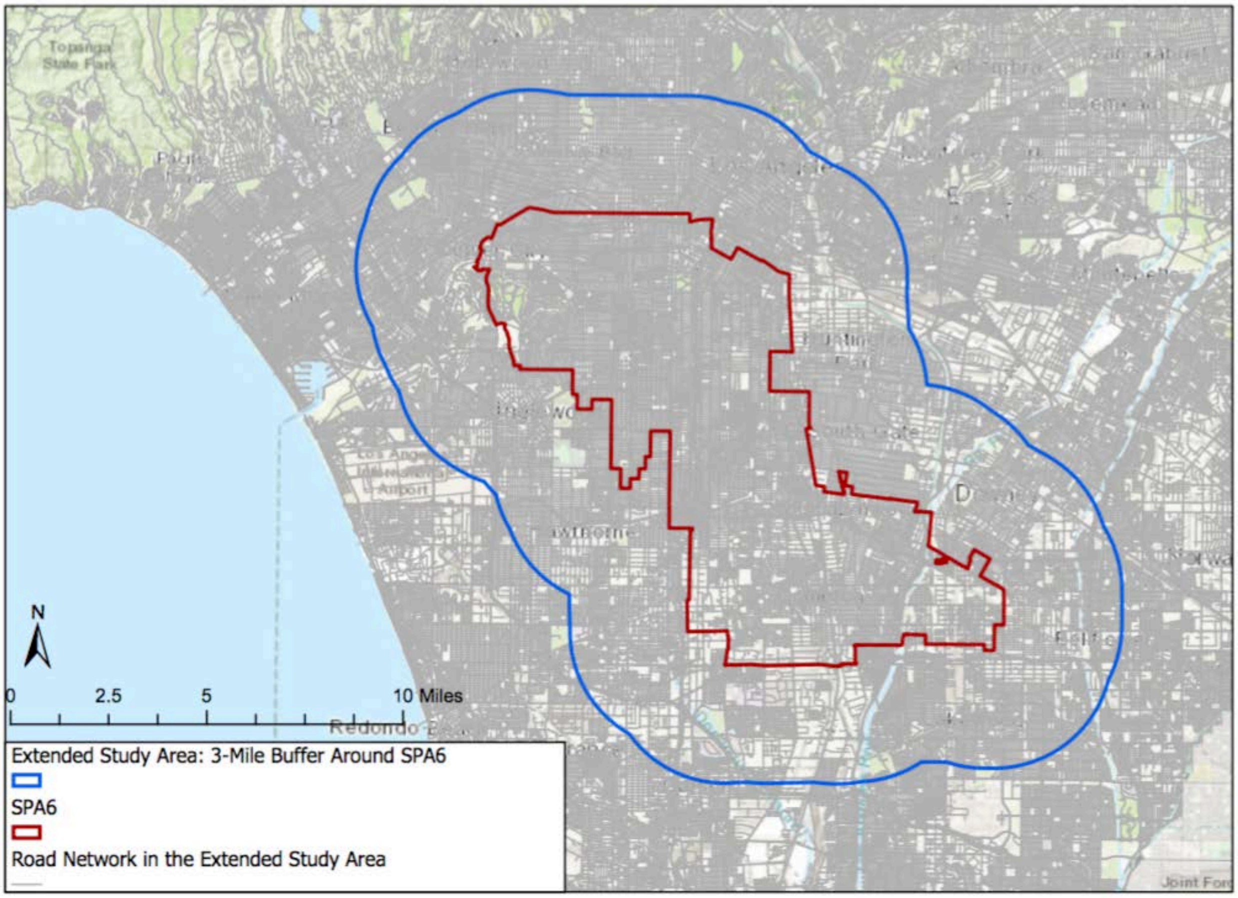

Figure 11. Road Network in the Extended Study Area

3.1.5. Existing Low-Cost Primary Care Facilities

Los Angeles County Department of Health Services maintains a dataset of primary care facilities that provide low-cost primary care. This dataset was used in the fuzzy overlay analysis to ensure candidate sites do not overlap with existing facilities in terms of service area and in the 2SFCA analysis to calculate accessibility scores. However, the Los Angeles County Department of Health Services only includes the name, address, contact information, service information, and business hours of the low-cost primary care facilities.

As discussed in Chapter 2, the way previous research uses the number of physicians as the indicator of primary care provision capacity is problematic since it neglects non-physician primary care providers and assumes equal amount of primary care provision per physician. This project employed a revised indicator that represents primary care provision capacity more realistically by accounting for the primary care provided by non-physician clinicians and the various working hours of different primary care providers. Since physicians are usually the core component of medical care, this study used their primary care provision capacity as the baseline supply unit following the path of previous research (e.g. Guagliardo 2004). However, unlike previous research which measure capacity by the number of physicians, this thesis defined the baseline unit of supply as the amount of primary care one physician can provide in an hour. This is to account for the various working hours of different primary care providers. For instance, the new indicator can account for the different amount of primary care provided by a facility with two physicians that opens for 40 hours a week and a facility with two physicians that opens for 20 hours a week.

This methodology also considered the work of physician assistants and nurse practitioners in its measure of provision capacity, since both are capable of diagnosing medical conditions, performing health examinations, treating illnesses, etc. (California Code, Business and Professions Code, BPC § 12714). However, physician assistants and nurse practitioners are legally required to work in collaboration with physicians and are usually under the supervision of physicians (California Code, Business and Professions Code, BPC § 12714). Thus, this study sets the primary care provision capacity of each physician assistant or nurse practitioner provides per hour as 0.5 unit of provision capacity, acknowledging both their important roles in primary care supply and their professional limitations. The calculation of the primary care service capacity *S* of each existing low-cost primary care facility j is defined below:

$$S_j = (MD_j * 1 + PA_j * 0.5 + NP_j * 0.5) * H_j$$

Where MD_j is the number of physicians at facility j, PA_j is the number of physician assistants at location j, NP_j is the number of nurse practitioners at location j, and H_j is the total business hours per week at location j. The primary care capacity each physician provides per hour is calculated as 1 unit of provision capacity.

The author identified the business hours of each low-cost primary care facility in the extended study area as well as the number of each type of primary care provider from the websites of the Los Angeles County Department of Health Services and low-cost primary care facilities. Figure 12 presents the existing low-cost primary care facilities within the extended study area and their service capacity according to the data provided by the Los Angeles County Department of Health Services.

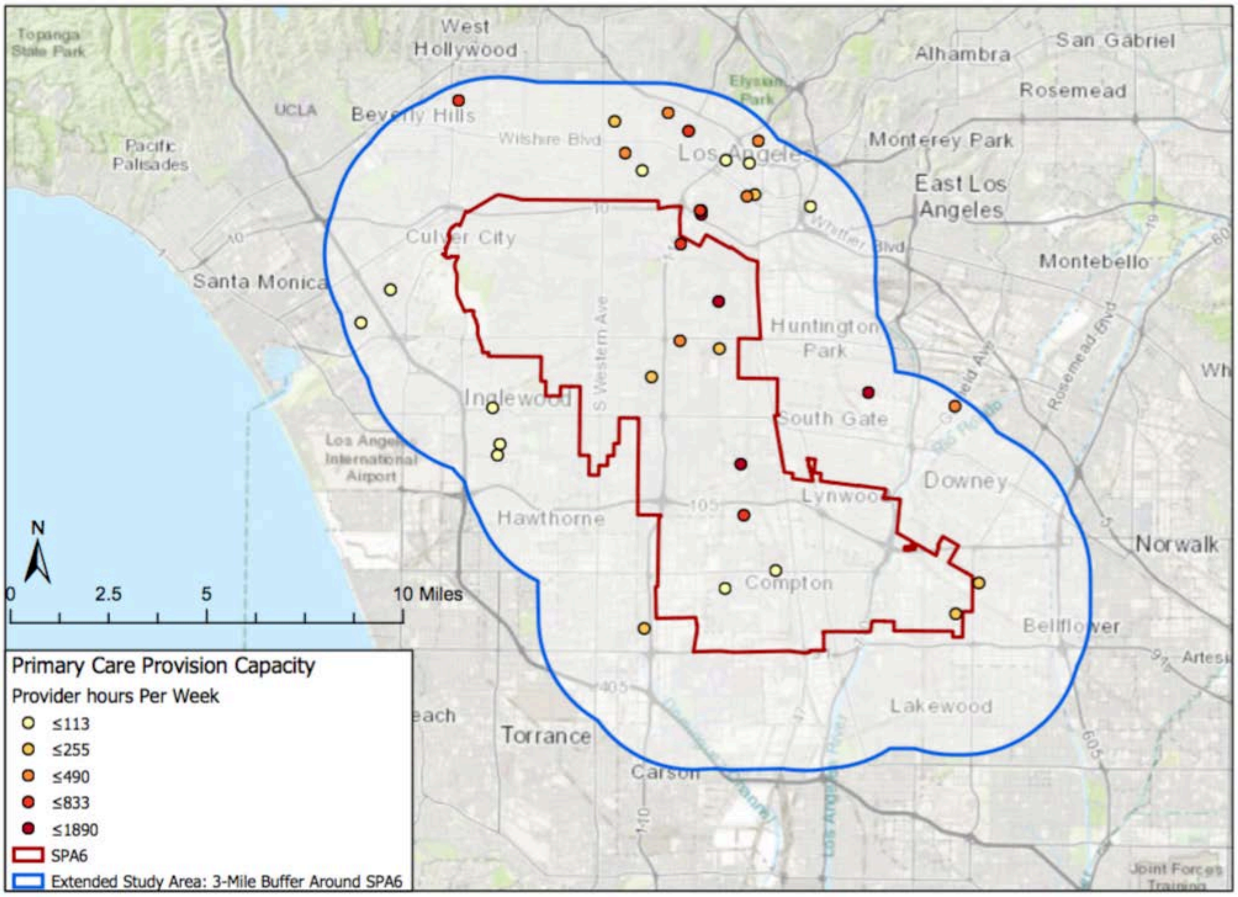

Figure 12. Location and Service Capacity of Existing Low-Cost Primary Care Facilities in the Extended Study Area

3.2. Site Selection Analysis

This section describes the methods used in the site selection stage of this analysis. Firstly, this section discusses the filtering process of all candidate sites that aims at increasing computational efficiency prior to site selection. This section then explains the reason for choosing fuzzy overlay as the site selection method. Lastly, this section details the work flow in the fuzzy overlay analysis.

3.2.1. Filtering Parcels

A first step of filtering out candidate sites that are definitely not suitable for the new low-cost primary care facility contributes to computational efficiency. This thesis adopted the three filtering criteria of zoning designation, vacancy status, and parcel size.

If a candidate parcel is not zoned for commercial uses, it would not be suitable for the purpose of this project regardless of its other attributes. Moreover, there are 502,889 parcels within the extended study area, most of which are not zoned for commercial uses. It would require a lot of computational power if this project conducted the fuzzy overlay analysis without first eliminating parcels with inappropriate zoning. As discussed in Chapter 2, a site for a primary care facility should have one of the eight commercial zoning designations. Since the study area is SPA6 of Los Angeles County, this project eliminated parcels zoned C-R (large-scale recreational uses), C-RU (agricultural activities), and CPD (maximum of 40% lot coverage), as these are unsuitable for a primary care facility in an urban study area.

Moreover, since the goal of this project is to select a suitable site for a new low-cost primary facility, it is also important to ensure site availability. Therefore, this project filtered out all non-vacant parcels.

Parcel size is another essential requirement for candidate sites. If an otherwise suitable parcel is too small to build a primary care facility, the parcel would be unfeasible for the goal of this project. If an otherwise suitable parcel is too large, too many financial resources would be spent on purchasing the parcel rather than primary care provision. But for a parcel that is neither too large or too small, the size does not matter for site suitability because the parcel size is positively correlated with primary care provision capacity, which can be used to calculate the impact of the new low-cost primary care facility on primary care accessibility using 2SFCA. Therefore, this project only eliminated parcels too large or too small in this filtering stage. As discussed in Chapter 2, a basic primary care facility with only one physician requires at least 2,750 square feet. Therefore, this analysis eliminated any candidate sites smaller than 2,750 square feet as they cannot accommodate the spatial needs of a primary care facility. Also discussed in Chapter 2, the largest parcel containing a facility that only provides low-cost primary care in Los Angeles County is around 25,000 square feet. In order to allow for more flexibility in the fuzzy overlay analysis, this project eliminated parcels over 30,000 square feet.

3.2.2. Site Selection Method

Chapter 2 reviews the two commonly used site selection methods, weighted overlay and fuzzy overlay. This thesis adopted the fuzzy overly method for the following two reasons. Firstly, the fuzzy overlay method is suitable for this thesis because the four key site selection criteria, proximity to public transit, distance from existing low-cost primary care facilities, land cost, and density of low-income populations, are all defined by continuous values with no clear cut-off points between suitable and unsuitable sites. Previous research has only suggested general directions of site suitability for these criteria instead of clearly distinguishable cut-off points of suitability, making the weighted overlay method an undesirable option.

Secondly, the fuzzy overly method is ideal for this thesis because the relationship between the overlay suitability and the four key site selection criteria is not linear. A desirable site for the new low-cost primary care facility should meet the requirements of all four key criteria simultaneously, which requires more flexible options to analyze the site selection criteria. The weighted overlay method is limited in this case because it can only generate overall site suitability as the weighted sum of all site selection criteria. By summing up the weighted values of each criteria, a site with extremely desirable values on some of the four key site selection criteria and undesirable values on others might have a high overall suitability if the weighted overlay method is applied. The fuzzy overlay method, however, allows both logical and mathematical operators in the analysis of different site selection criteria. The Fuzzy And method offered in the fuzzy overlay analysis is ideal to combine the four key site selection criteria since it returns the minimum value of all criteria, which ensures the final high-ranking sites are likely to meet all site selection criteria.

3.2.3. Fuzzy Membership Procedures

After determining the site selection method, this thesis assigned functions to the remaining four criteria to create fuzzy membership layers for the fuzzy overlay analysis.

3.2.3.1. Proximity to Public Transit

The closer to public transit a parcel is, the more suitable it is for a new low-cost primary care facility. Therefore, this project used the Fuzzy Small transformation function for the proximity to public transit criterion. With the Fuzzy Small transformation function, values larger than the midpoint have a lower possibility of being a member and values smaller than the midpoint have a higher possibility of being a member (Esri 2018a). Figure 13 shows a diagram summarizing the workflow for creating this fuzzy membership layer:

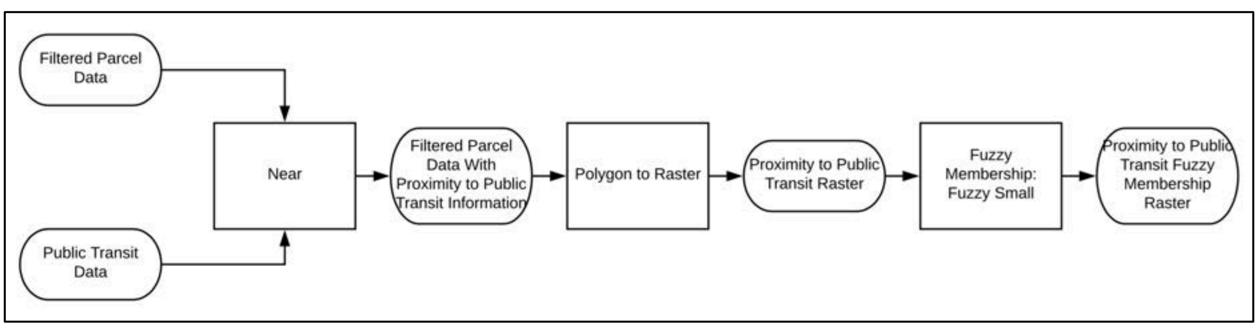

Figure 13. Workflow for the Proximity to Public Transit Fuzzy Membership Layer

3.2.3.2. Distance to Existing Low-Cost Primary Care Facilities

A desirable candidate site should be as far away from the closest existing low-cost primary care facility as possible. This project therefore employed the Fuzzy Large transformation function for the distance to existing low-cost primary care facilities criterion. This function allows values larger than the midpoint to have a higher possibility of being a member and values smaller than the midpoint to have a lower possibility of being a member (Esri 2018a). Figure 14 shows a diagram summarizing the workflow of this distance to existing low-cost primary care facilities layer:

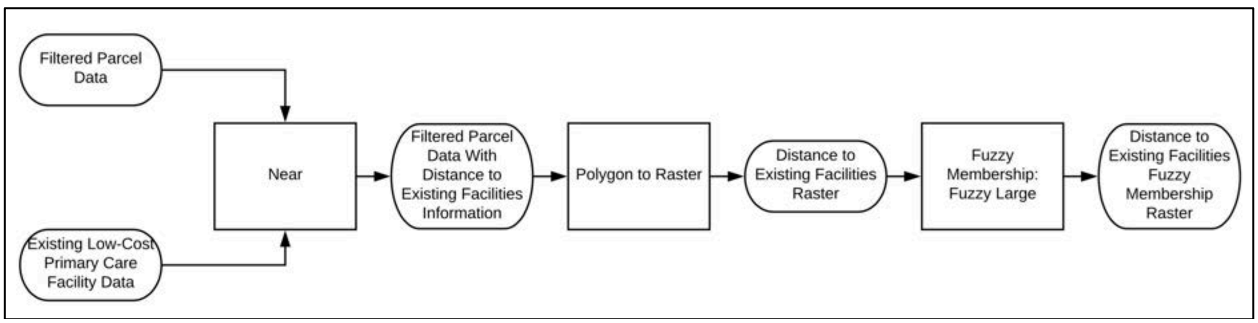

Figure 14. Workflow for the Distance to Existing Low-Cost Primary Care Facilities Fuzzy Membership Layer

3.2.3.3. Land Cost

A desirable site should have as low per unit land cost as possible. Since the area of candidate parcels varies, the total values of parcels are not comparable. This project first calculated the land price per square foot for all candidate parcels and chooses the Fuzzy Small transformation function for the land price per square foot. This function allows values larger than the midpoint to have a higher possibility to be a member and values smaller than the midpoint to have a lower possibility to be a member (Esri 2018a), namely, parcels with cheaper per square foot land price are more likely to be members. Figure 15 shows a diagram summarizing the workflow of this land cost layer:

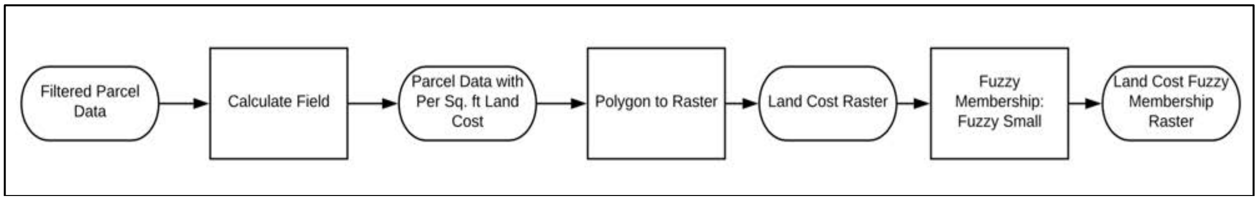

Figure 15. Workflow for the Land Cost Fuzzy Membership Layer

3.2.3.4. Low-Income Populations

The last criterion for the site selection process is the proximity to targeted service recipients, namely, low-income residents in SPA6. A desirable site for the new low-cost primary care facility should be close to as many low-income residents as possible. This project chose the Fuzzy Large transformation function for the low-income population criterion because this function allows values larger than the midpoint to have a higher possibility of being a member and values smaller than the midpoint to have a lower possibility of being a member (Esri 2018a). In order to measure the number of low-income residents close to a candidate site, this project created a one-mile buffer around all candidate parcels and calculated the number of low-income residents within each buffer. Since the American Community Survey data used in this project aggregates demographic data at the census tract level, this project assumed even distribution of population within each census tract for this step. The number of targeted service recipients for each candidate site was calculated by intersecting the 1-mile buffer with census tracts and then calculating the number of low-income residents in the overlapping area with the Tabulate Intersection tool offered in ArcGIS Pro. For instance, with the Tabulate Intersection tool, if a 1-mile buffer contains 100% of census tract 1, 80% of census tract 2, and 30% of census tract 3, the total population of the 1-mile buffer is the sum of 100% of the population in census tract 1, 80% of the population in census tract 2, and 30% of the population in census tract 3. While assuming even population distribution within census tracts is not the most ideal way to reflect population information accurately, it still has advantages over the alternative method that uses census tract centroids as population points. This step also better accounted for primary care accessibility for potential service recipients who have no access to either private vehicles or public transit, as one mile is a reasonable distance for an average person to walk. Figure 16 shows a diagram summarizing the workflow of this low-income population layer:

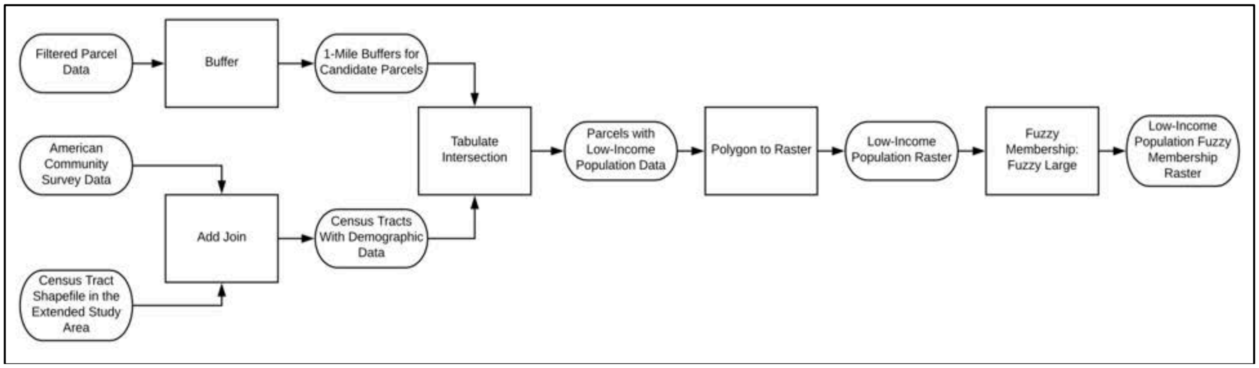

Figure 16. Workflow for the Low-Income Population Layer

3.2.4. Fuzzy Overlay Analysis

This section explains the fuzzy overlay process used to combine the fuzzy membership layers for the site selection.

This project chose the AND operator for the fuzzy membership analysis because a desirable site for the new low-cost primary care facility should satisfy all four site selection criteria to the greatest extent possible. The AND overlay method returns the minimum value among all input fuzzy membership layers as the result, and thus the cells with high output values are more likely to meet all site selection criteria (Mitchell 2012). The diagram in Figure 17 below presents the workflow for the fuzzy overlay analysis:

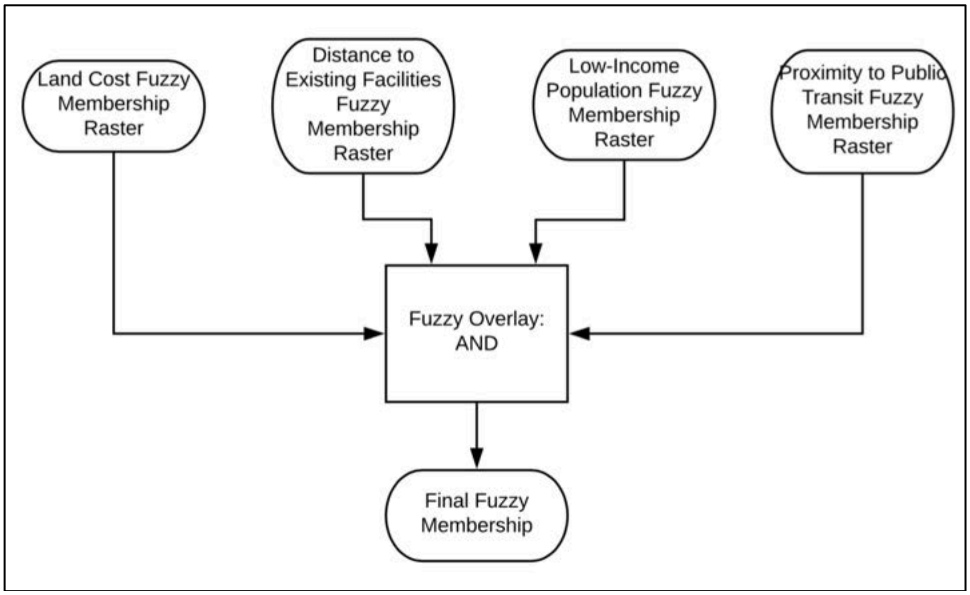

Figure 17. Fuzzy Overlay Workflow

The site selection analysis with the fuzzy overlay method is likely to have results where more than one candidate site has the highest possibility or several parcels have similar high possibility. Therefore, instead of simply comparing the final fuzzy membership values, this project included a novel evaluation stage to further assess the suitability of candidate sites with high fuzzy membership values with the 2SFCA method. The following section discusses how this project employed the 2SFCA method to evaluate how the candidate sites with high scores affect health care accessibility for low-income residents of SPA6.

3.3. Candidate Site Evaluation with 2SFCA

This section describes the process for evaluating whether the addition of a low-cost primary care at each candidate site would improve health care accessibility for residents of SPA6. To set a baseline from which to judge candidate sites, the health care accessibility for each census tract in SPA6 given existing conditions was calculated. Then, the impact on accessibility for each census tract was assessed with the addition of each candidate site. The candidate site that brings the largest increase in the sum of accessibility scores in all census tracts within SPA6 was the most suitable site for the new low-cost primary care facility. Figure 18 below summarizes the workflow to calculate the baseline accessibility scores and the updated accessibility scores with the addition of each candidate site for the census tracts in SPA using the 2SFCA method:

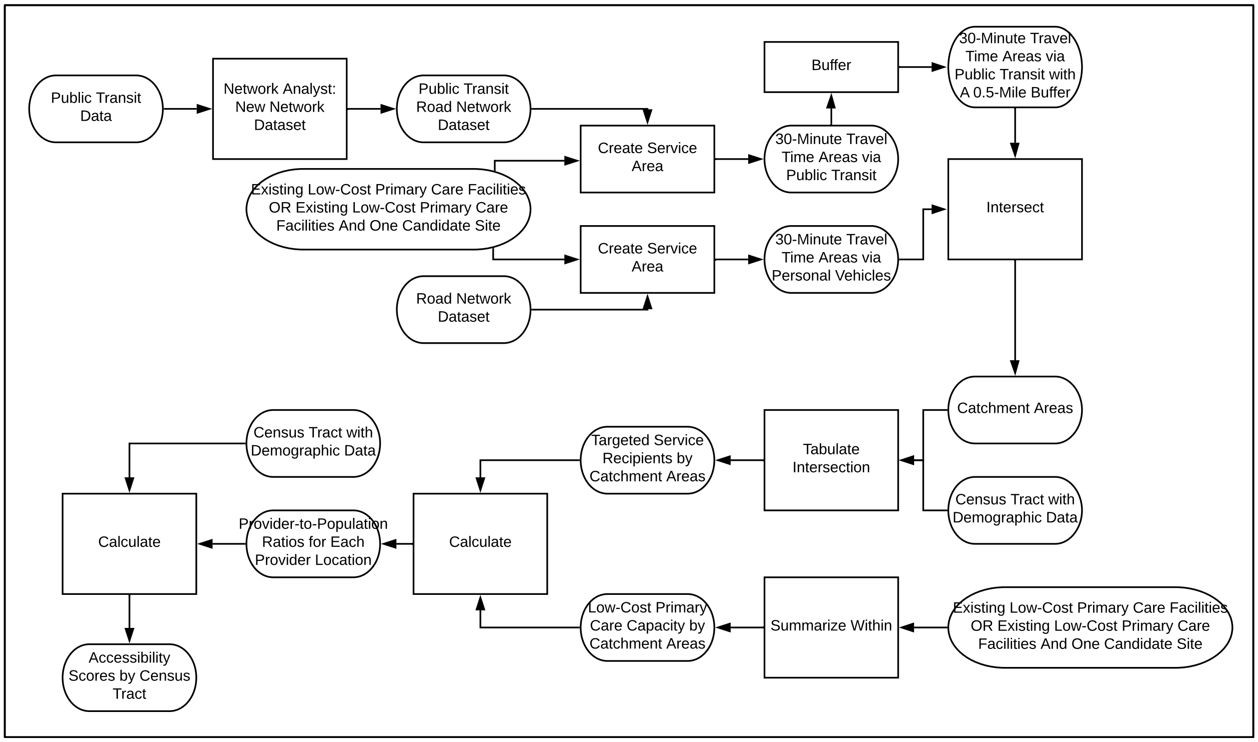

Figure 18. 2SFCA Workflow

The first step was to define catchment areas. Conventionally, catchment areas for 2SFCA analyses are defined by driving time via private vehicle as discussed in Chapter 2. This project strived to account for the lower car ownership among the low-income residents; it therefore defined catchment areas with both travel time via both private vehicle and public transit. In terms of travel time via private vehicle, this project chose the 30-minute threshold, proposed by Lee (1999) and accepted by Wang and Luo (2005). The travel time via private vehicle from each population point, namely, the census tract centroids, can be calculated through with the Create Service Area tool using the Los Angeles road network dataset acquired previously.

In addition to travel time via private vehicle, this project also addressed travel time via public transit. While there is no up-to-date road network dataset available for public transit in Los Angeles County, it is possible to construct a road network dataset with the public transit data acquired from the U.S. EPA Smart Location Dataset with ArcMap. Similar as travel time via private vehicle, this project selected 30 minutes as the threshold for travel time via public transit. Considering the lower density of public transit routes in comparison to road network, this project also included any area within 0.5 mile, a reasonable walking distance, from public transit stops as part of the service areas. Therefore, this project defined catchment area of a given low-cost primary care facility or population center as the intersection of the 30-minute public transit travel time polygon with a 0.5-mile buffer and the 30-minute private vehicle travel time polygon to ensure a low-income resident can access this site within a reasonable amount of time in Los Angeles traffic regardless of her car ownership status.

Since the population data for this project is aggregated at census tract level, it is necessary to define the calculation of targeted service recipients for the candidate sites. As discussed previously in this Chapter, the Tabulate Intersection tool provides a more realistic result than assuming all residents concentrate on the centroid of a census tract. Therefore, this project also adopted the Tabulate Intersection tool to estimate the number of low-income residents in catchment areas.

Calculating accessibility scores also requires calculating the low-cost primary care provision capacity for the candidate sites. As discussed in Chapter 2, the parcel size is positively correlated with the number of primary care providers a candidate site can host. This project first calculated the number of physicians each candidate site can host based on its size and then calculated the primary care provision capacity with the assumption that the facility is open for 40 hours a week. The assumption for business hours per week is based on the average weekly business hours of the 34 existing low-cost primary care facilities in the extended study area. The actually average business hours per week for the 34 existing facilities is 42.69 and this project adopted 40 for easy computation.

Since the accessibility scores calculated with the 2SFCA method are quantitative and intuitive, it is relatively easy to compare the impacts on low-cost primary care accessibility brought by each of the candidate site using the sum of accessibility scores in SPA6. This thesis employed the 2SFCA method to calculate accessibility scores for each census tract in SPA6 first with only the existing low-cost primary care facilities and used the sum of the accessibility scores as the baseline for evaluating the shortlist of candidate sites generated from the fuzzy overlay analysis. This project then calculated accessibility scores for each census tract respectively with each final candidate site added. Next, this thesis compared the sum of the primary care accessibility scores with the addition of each final candidate to the baseline, the candidate site that leaded to the highest increase in the sum of primary care accessibility scores was the overall most suitable site for a new low-cost primary care facility for SPA6. For instance, if the sum of the baseline accessibility scores with only existing low-cost primary care facilities in SPA6 is 100, the sum of the accessibility scores with the addition of candidate site A is 103, the sum of the accessibility scores with the addition of candidate site B is 108, the sum of the accessibility scores with the addition of candidate site C is 101, candidate site B would be the most suitable site for a new low-cost primary care facility for improving primary care accessibility for low-income populations in SPA6.

The following chapter presents the results of this thesis.

Chapter 4 Results

This chapter first describes the results from the initial filtering process before explaining the fuzzy overlay analysis and the short list of candidate sites generated from it. Then, this chapter demonstrates the evaluation of the short list of candidate sites using 2SFCA analysis and presents the final results.

The initial filtering process reduced the number of candidate sites from 502,889 to 2,096 based on the three filtering criteria of zoning designation, vacancy status, and parcel size. The fuzzy overlay analysis examined the 2,096 candidate sites using the four criteria of distance to existing low-cost primary care facilities, distance to public transit, land cost, and number of low-income residents in close proximity. This analysis generated 13 candidate sites with membership values above 0.9 as a short list of candidate sites to be further evaluated with the 2SFCA analysis.

The 2SFCA analysis first generated the service area for each of the 13 final candidate sites based on travel time via private vehicles and via public transit. After calculating the service capacity at each final candidate site based on the land available, the 2SFCA analysis calculated the low-cost primary care accessibility scores for each census tract in SPA6 with only existing low-cost primary care facilities as baseline and with the addition of each final candidate site in order to evaluate their impacts on low-cost primary care accessibility for low-income populations in SPA6. The 2SFCA analysis indicated the candidate site at 13910 Wilmington Avenue, Compton, CA, 90250 as the most suitable site for a new low-cost primary care facility that serves SPA6. The 2SFCA analysis also demonstrated how other final candidate sites affect the low-cost primary care accessibility for the reference of potential decision makers.

4.1. Initial Filtering

The initial filtering process significantly reduced the number of candidate sites with the three filter criteria. Among the total 502,889 parcels in the extended study area, 34,345 parcels are zoned for commercial uses, and of these, 10,591 have zoning designations that are suitable for primary care facilities such as C-1, C-2, C-3, C-H, or C-M. Among the 10,591 parcels with suitable zoning, 2,980 parcels are vacant. After excluding sites smaller than 2,750 square feet and larger than 30,000 square feet, the number of candidate sites reduced to 2,096. Figure 19 below presents the 2,096 candidate sites after the filtering process:

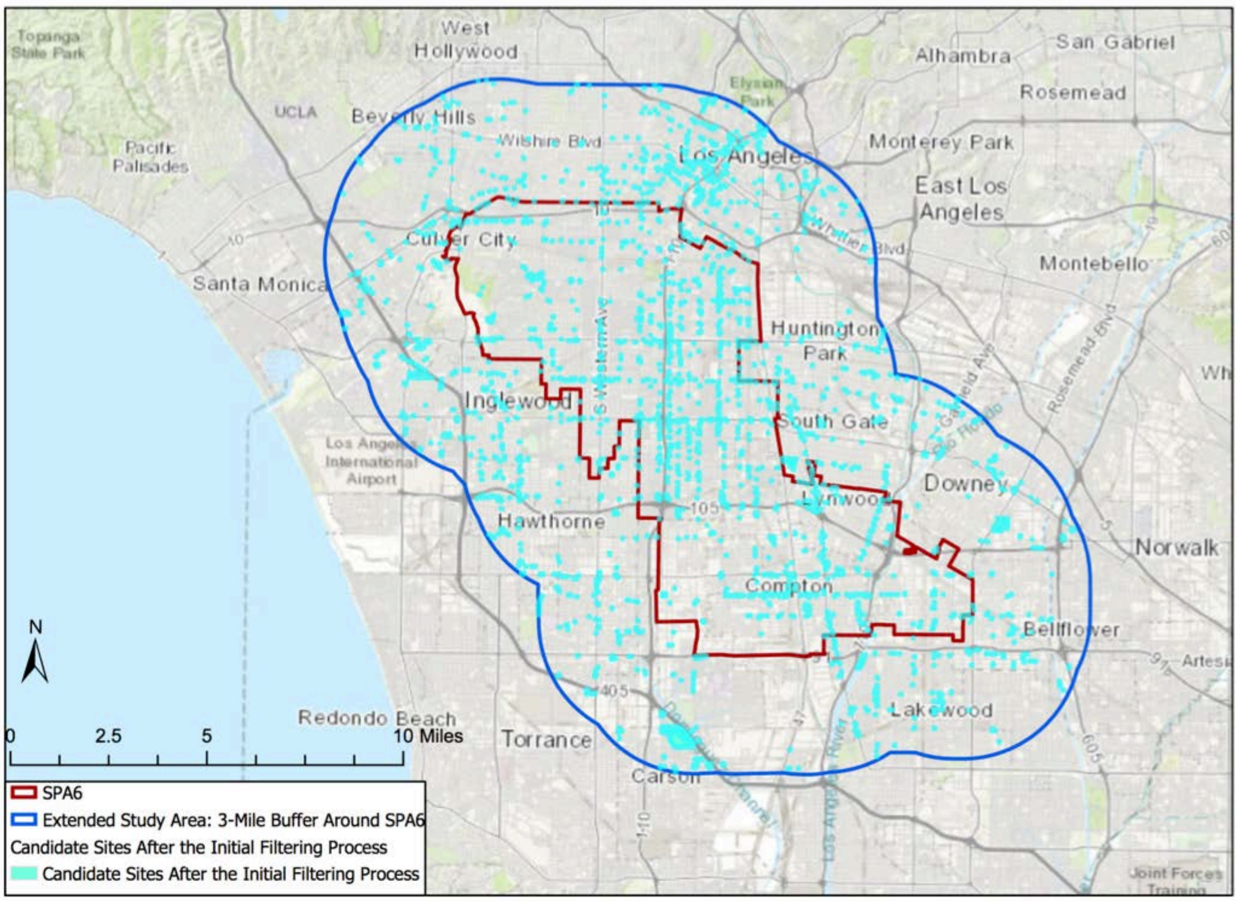

Figure 19. Candidate Sites After the Initial Filtering Process

4.2. Fuzzy Overlay Analysis

As discussed in Chapter 3, this thesis used fuzzy overlay analysis to select suitable sites for the new low-cost primary care facility for low-income populations in SPA6 based on four criteria after filtering out the sites that were not eligible because of zoning regulations and parcel size. The fuzzy overlay analysis first assigned fuzzy membership values to the 2,096 candidate sites based on the four criteria, including distance to the closest existing low-cost primary care facility, distance to the closet public transit stop, land cost per square foot, and number of low-income residents within a 1-mile radius. Figures 18-21 below summarize the fuzzy membership values assigned to the candidate sites for each of the four criteria. For the sake of better visualization, this thesis converted the fuzzy membership raster layers to vector point layers.

Figure 20 below presents the fuzzy membership values for all candidate sites based on their distance to the closest existing low-cost primary care facility. As discussed in Chapter 2, a desirable site for a new low-cost primary care facility should not be too close to an existing one in order to avoid overlapping service areas. The distance from a candidate site to the closest existing low-cost primary care facility ranges from 75 feet to 4.5 miles. This thesis used the Fuzzy Large transformation function to assign fuzzy membership to the candidate sites, which allowed values larger than the midpoint to have higher fuzzy membership values, and generated fuzzy membership values range from 1.43e-11 to 0.97.

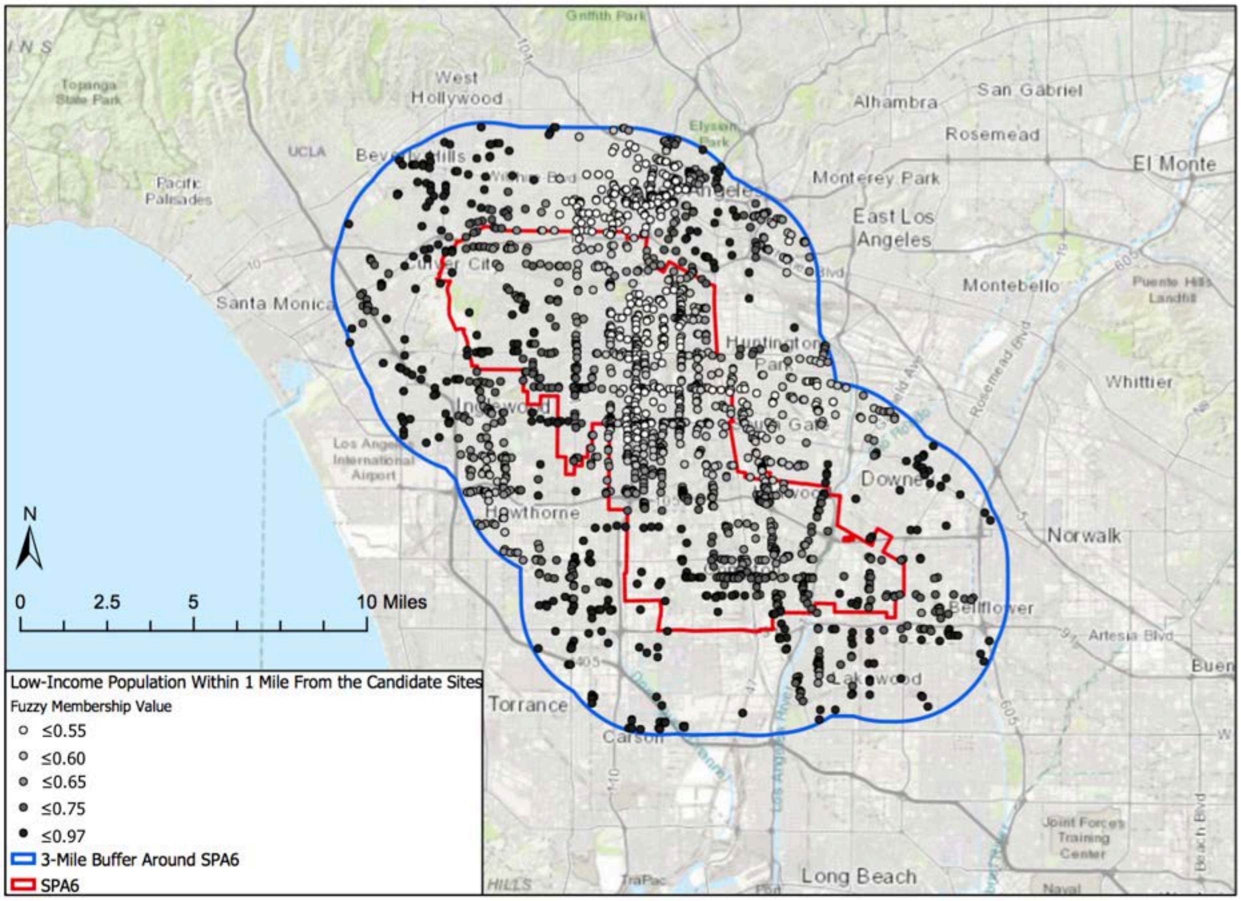

Figure 20. Fuzzy Membership Values Based on Distance to the Closest Existing Low-cost Primary Care Facility

Figure 21 below shows the fuzzy membership values for all candidate sites based on their distance to the closest public transit stop. As discussed in Chapter 2, a desirable site for a new low-cost primary care facility should as close to public transit stops as possible in order to ensure accessibility via public transit. This criterion is particularly important for the selection of a primary care facility for the low-income populations as the car ownership rate is significantly lower among them. The distance from a candidate site to the closest public transit stop ranges from 13 feet to 1.02 miles. This thesis used the Fuzzy Small transformation function to assign fuzzy membership to the candidate sites, which allowed values smaller than the midpoint to have higher fuzzy membership values, and generated fuzzy membership values range from 0.03 to 1.

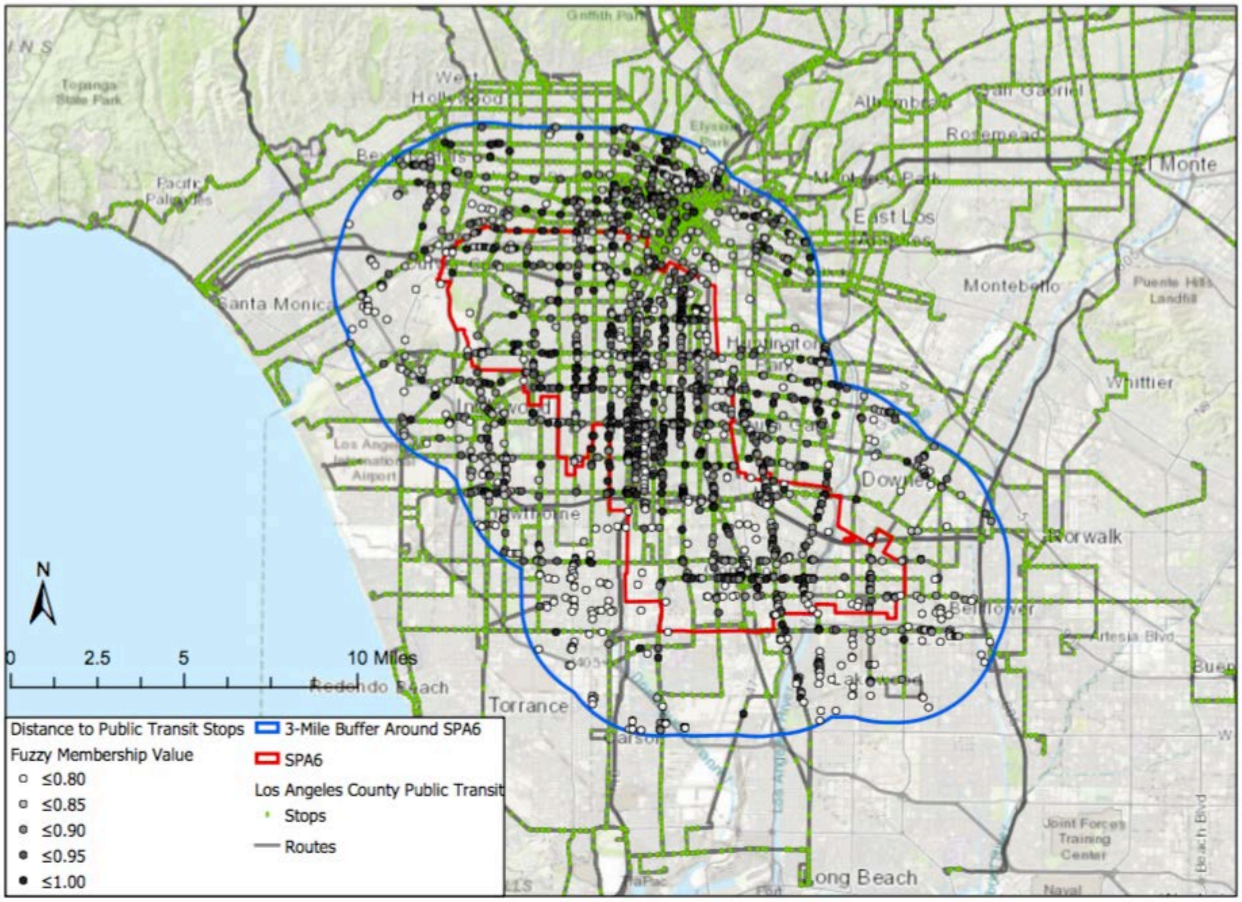

Figure 21. Fuzzy Membership Values Based on Distance to the Closest Public Transit Stop

Figure 22 below shows the fuzzy membership values for all candidate sites based on their land value per square foot. As discussed in Chapter 2, a desirable site for a new low-cost primary care facility should be as cheap as possible. Since the area of candidate sites varies, land value per square foot is more comparable in comparison to total land value. The land value per square foot for all candidate sites ranges from \$23 to \$97. This thesis used the Fuzzy Small transformation function to assign fuzzy membership to the candidate sites, which allowed values smaller than the midpoint to have higher fuzzy membership values, and generated fuzzy membership values range from 0.87 to 1.

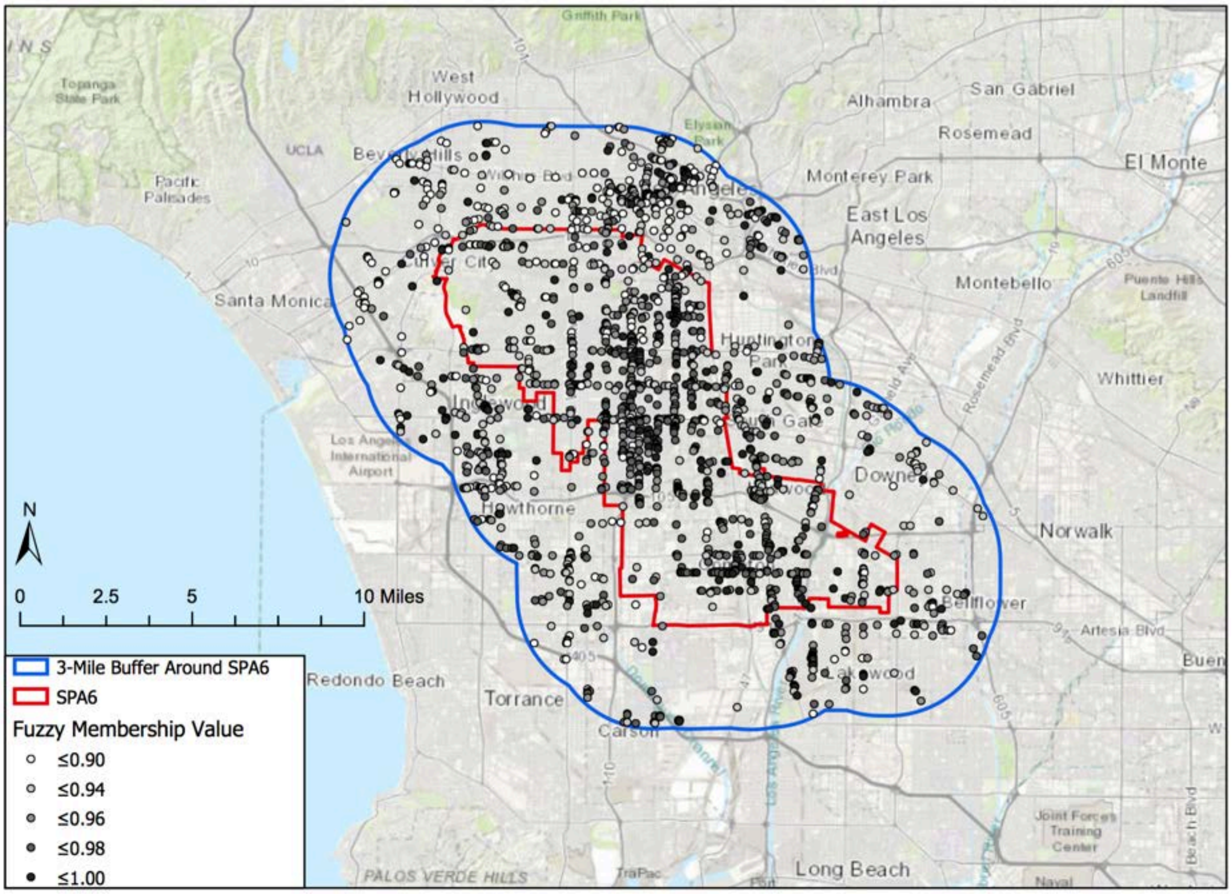

Figure 22. Fuzzy Membership Values Based on Land Value Per Square Foot

Figure 23 below shows the fuzzy membership values for all candidate sites based on the estimated number of low-income residents within a 1-mile radius from each candidate site. As discussed in Chapter 2, a desirable site for a new low-cost primary care facility should be as cheap as possible. Instead of using the centroids of census tract as population points like some of the previous research discussed in Chapter 2 does, this thesis assumed even distribution of populations in census tracts and used the Tabulate Intersection tool offered in ArcGIS Pro to estimate the number of low-income residents within each 1-mile buffer around each candidate sites. While the assumption that the population density within each census tract is still not accurate, it provides a more realistic estimate than treating the census centroids as population points. The number of low-income residents within a 1-mile buffer around each candidate site ranges from 2,164 to 74,515. This thesis used the Fuzzy Large transformation function to assign fuzzy membership to the candidate sites, which allowed values greater than the midpoint to have higher fuzzy membership values, and generated fuzzy membership values range from 0.33 to 0.94.

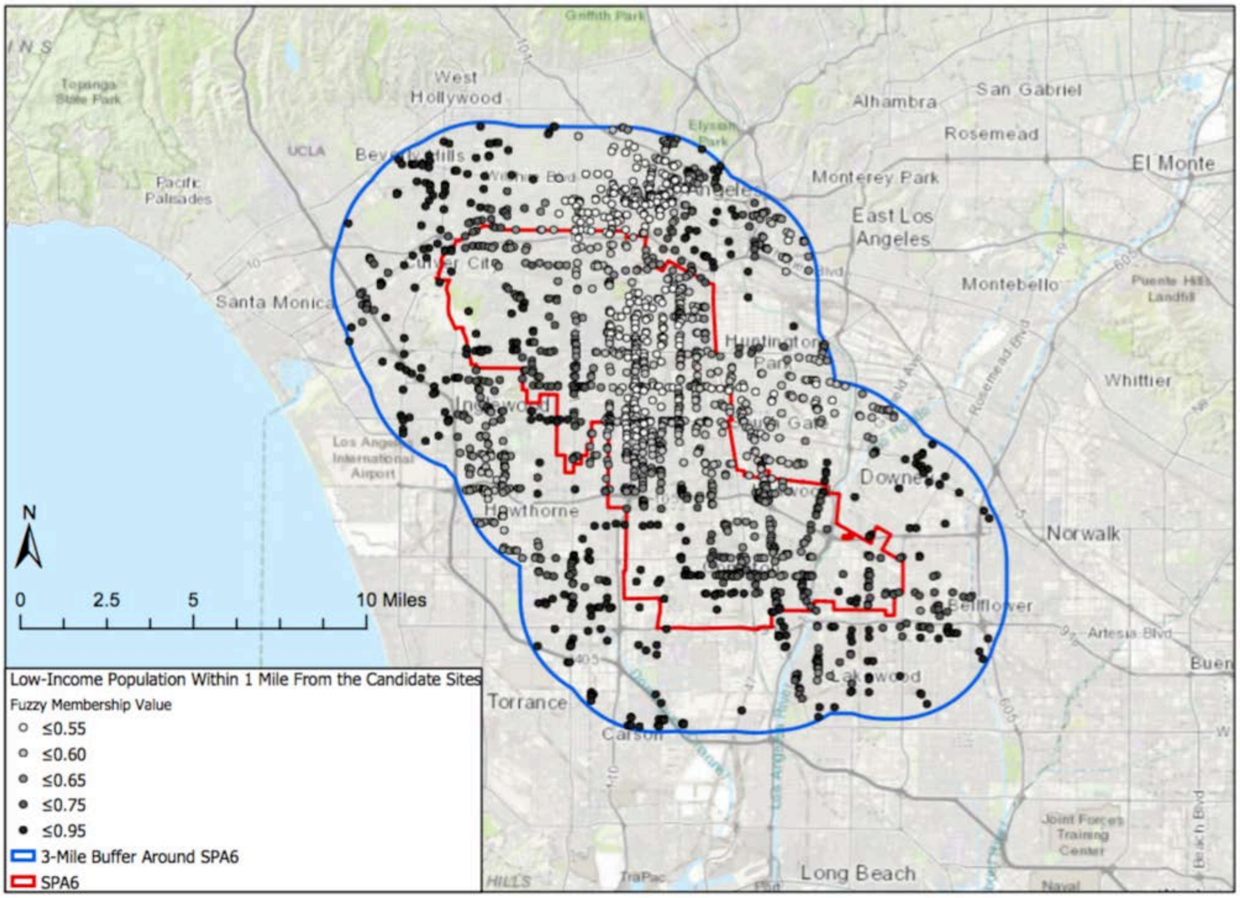

Figure 23. Fuzzy Membership Values Based on the Estimated Number of Low-Income Residents within 1 Mile from Candidate Sites

After assigning fuzzy membership based on the four site selection criteria, this thesis conducted the fuzzy overlay analysis using the Fuzzy AND overlay type and generated final fuzzy membership values for the candidate sites. Fuzzy AND provides the minimum fuzzy membership value from all fuzzy overly criteria, which ensures the candidate sites that have high final fuzzy overlay membership scores satisfy all site selection criteria. Final fuzzy membership scores range from 1.434E-11 to 0.969, with an average score of 0.168 and a standard deviation of 0.244. Among all candidate sites in the fuzzy overlay analysis, 13 candidate sites have final fuzzy membership scores higher than 0.9. Figure 24 below presents the final fuzzy membership values for the candidate sites.

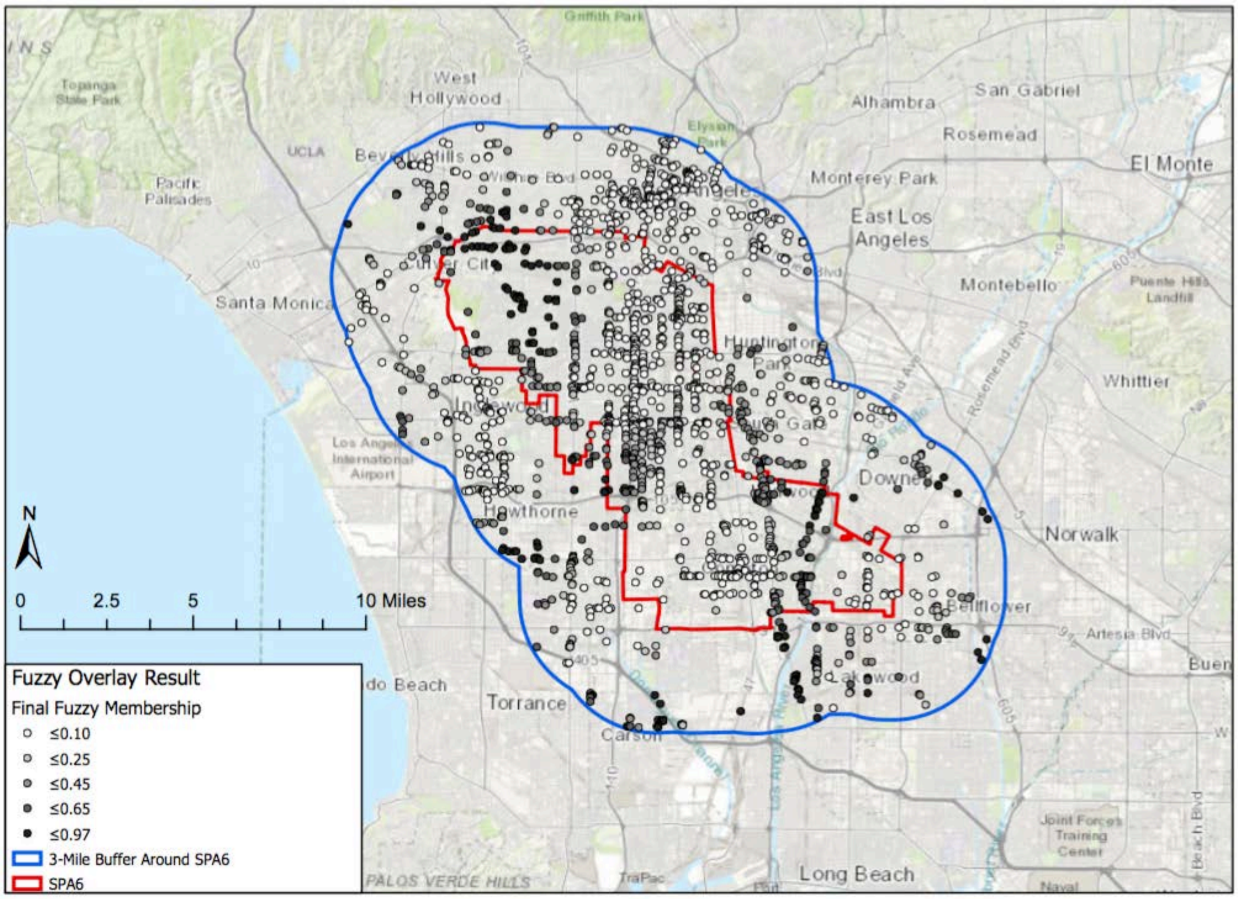

Figure 24. Final Fuzzy Membership Values for Candidate Sites

The 13 candidate sites with final fuzzy membership values higher than 0.9 are the final candidate sites in this project. Table 5 presents the shortlist of the final candidate sites to be further evaluated with the 2SFCA method. These final candidate sites are arranged by their final fuzzy membership scores in a descending order.

Table 5. Short List of Candidate Sites with Fuzzy Membership Values of 0.9 and Above

ID	Address	Size (Sq. Ft.)	Final Fuzzy Membership Value
1	1532 FIRESTONE BLVD, LOS ANGELES, CA, 90001	4870.179248	0.969193935
2	4130 FLORENCE AVE, BELL, CA, 90201	16323.30486	0.945967317
3	8001 SANTA FE AVE, HUNTINGTON PARK, CA, 90255	21470.54491	0.923763096
4	2603 GRAND AVE, HUNTINGTON PARK, CA, 90255	8135.013437	0.921251476
5	2184 FIRESTONE BLVD, LOS ANGELES, CA, 90002	3372.569554	0.920206487
6	2876 E FLORENCE AVE, HUNTINGTON PARK, CA, 90255	11653.9327	0.919949174
7	7721 COMPTON AVE, LOS ANGELES, CA, 90001	5539.405809	0.919698536
8	2182 FIRESTONE BLVD, LOS ANGELES, CA, 90002	3141.668533	0.918887079
9	7718 WILCOX AVE, CUDAHY, CA, 90201	22860.88452	0.915940046
10	1447 E 73RD ST, LOS ANGELES, CA, 90001	3756.327908	0.914339483
11	1754 FIRESTONE BLVD, LOS ANGELES, CA, 90001	4687.389735	0.91266644
12	13910 WILMINGTON AVE, COMPTON, CA, 90250	24312.85478	0.91241771
13	306 N. CENTRAL AVE, COMPTON, CA, 90220	8858.312761	0.905847728

Figure 25 below shows the locations of the candidate sites with fuzzy membership values of 0.9 and above as final candidate sites in the map context.

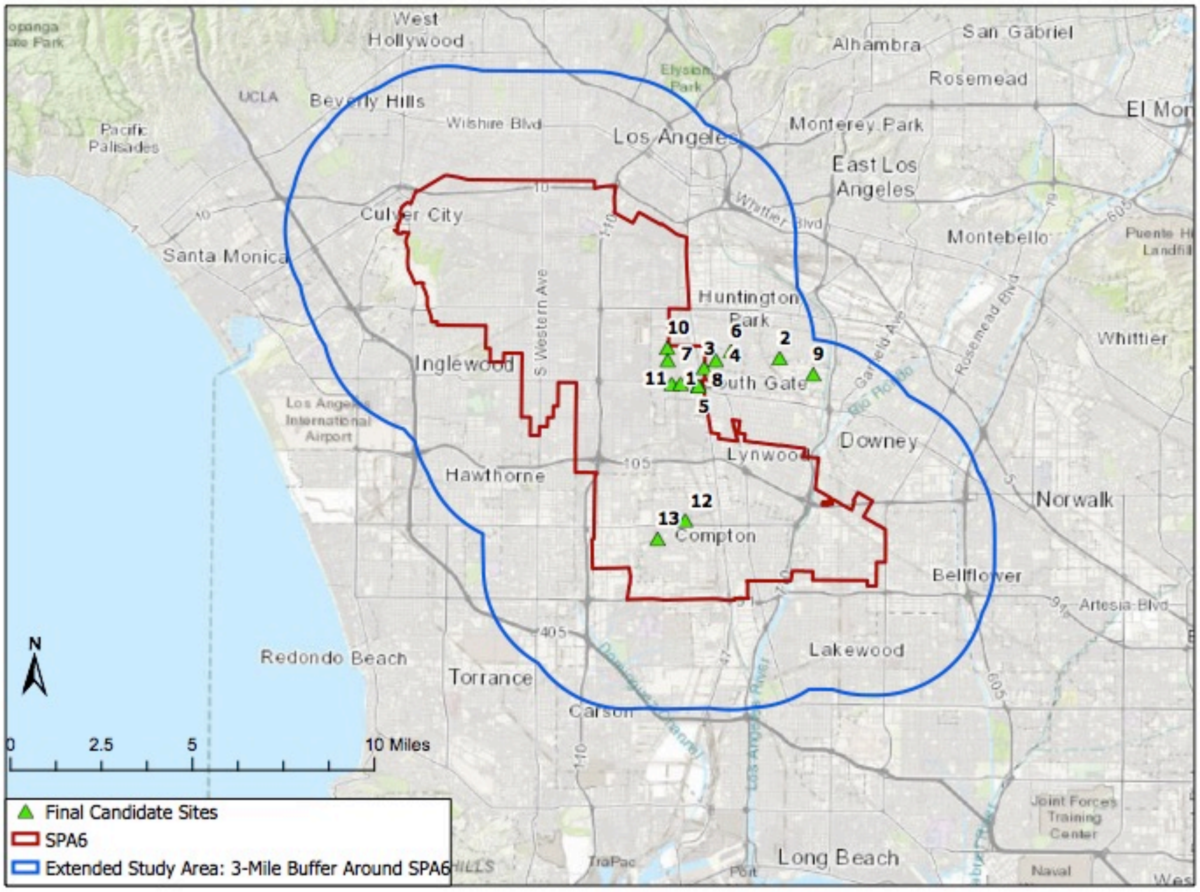

Figure 25. Final Candidate Sites

4.3. 2SFCA Analysis and Recommended Sites

This section discusses the results of the 2SFCA analysis for the 13 candidate sites with the highest final fuzzy membership values from the fuzzy overlay analysis. This section first presents the catchment areas for existing low-cost primary care facilities and the 13 final candidate sites based on travel time via both private vehicles and public transit and then shows the impacts of each final candidate site on the accessibility scores for the census tracts in SPA6.

4.3.1. Catchment Area

As discussed in Chapter 3, this thesis defines catchment areas by travel time via both private vehicle and public transit in order to account for the lower care ownership among the low-income residents. The catchment area for a given low-cost primary care facility or population center is the intersection of its 30-minute service area via private vehicle and its 30-minute service area via public transit with a 0.5-mile buffer. The 0.5-mile buffer around the 20-minute service area via public transit is to include areas within walking distance of public transit. This sub-section presents the catchment areas for existing low-cost primary care facilities, final candidate sites, and the census tracts in SPA6.

This project created 30-minute travel time areas via private vehicle and the 30-minute travel time areas plus a 0.5-mile buffer via public transit for existing low-cost primary care facilities in preparation of creating the catchment areas of these facilities. Since the travel areas overlap with each other to an extent where it is difficult to visualize all travel time areas in one map, Figure 26 only presents the 30-minute travel time area via private vehicle and the 30-minute travel time area plus a 0.5-mile buffer via public transit for existing low-cost primary care facility 27, Martin Luther King, Jr. Outpatient Center, as an example. As indicated in the map, the two sets of travel time areas are significantly different, which supports this thesis's choice of incorporating both travel methods in defining catchment areas for a new low-cost primary care facility that aims at increasing affordable primary care accessibility for low-income residents in SPA6. The final catchment area for a given existing low-cost primary care facility is the intersection of its 30-minute travel time areas via private vehicle and its 30-minute travel time areas plus a 0.5-mile buffer via public transit.

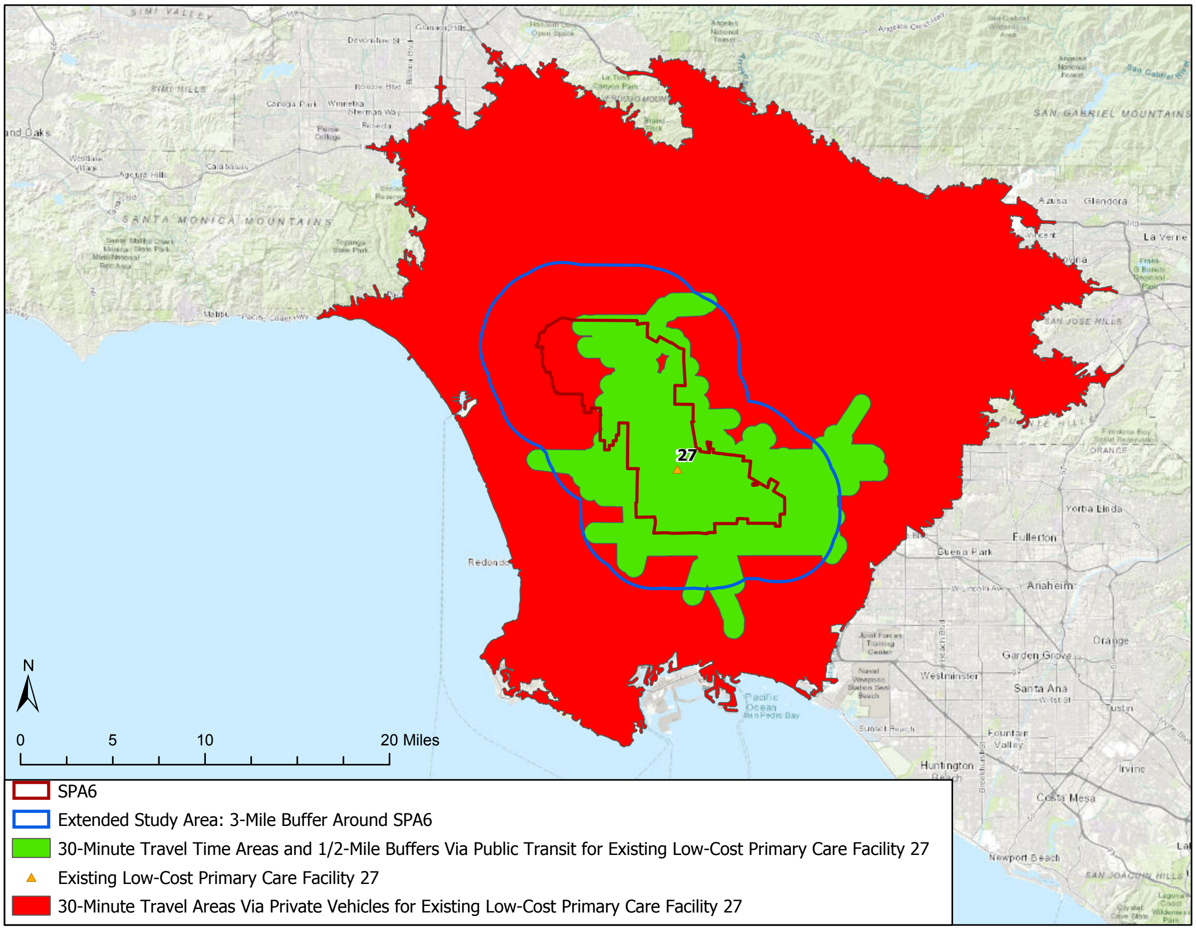

Figure 26. 30-Minute Travel Time Areas Via Private Vehicle and Public Transit for Existing Low-Cost Primary Care Facility 27

This project also created 30-minute travel time areas via private vehicle and the 30-minute travel time areas plus a 0.5-mile buffer via public transit for the 13 final candidate sites. Due to the similar problem of the overlapping of travel time areas, Figure 27 only presents the 30-minute travel areas via private vehicle and public transit for final candidate site 12 as an example.

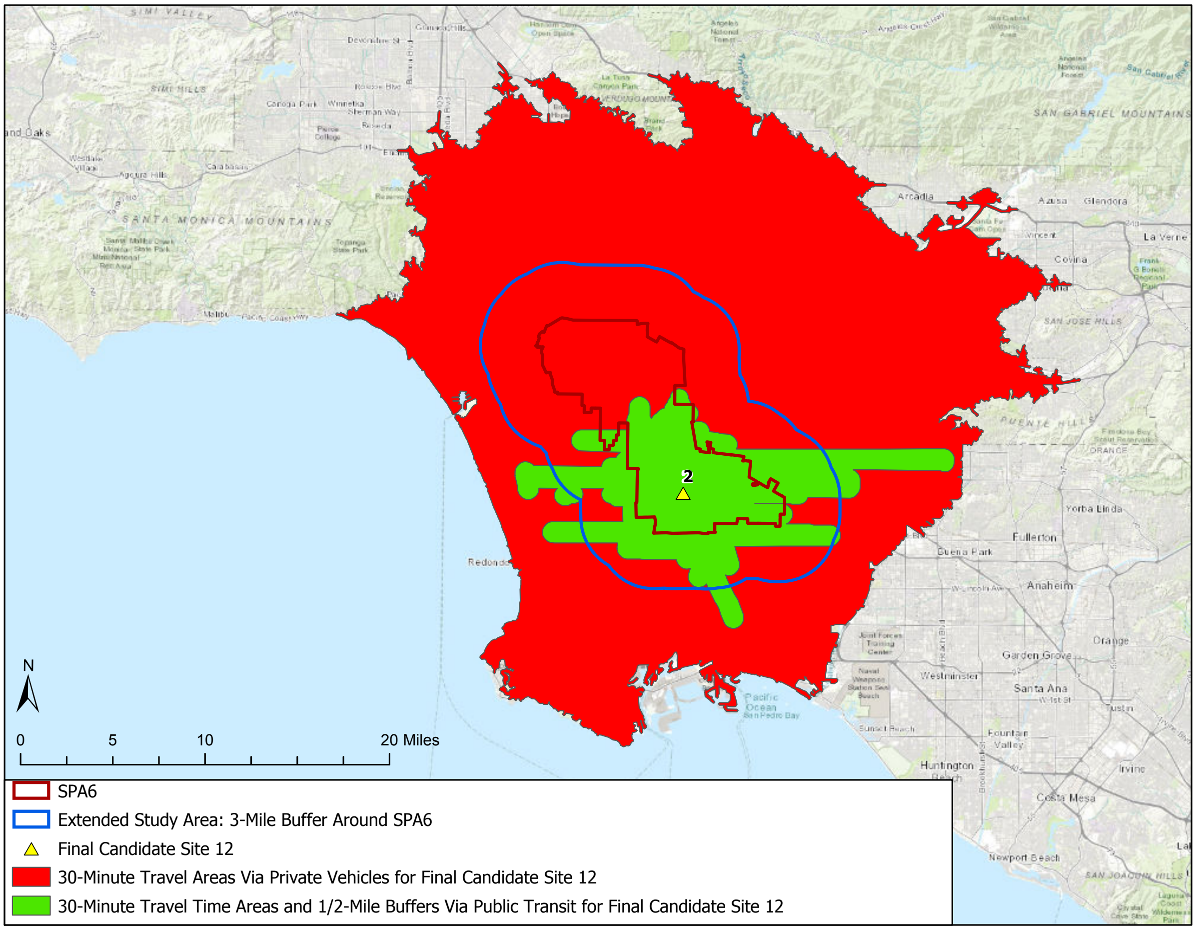

Figure 27. 30-Minute Travel Time Areas Via Private Vehicle and Public Transit for Final Candidate Site 12

Similarly, this project created 30-minute travel time areas via private vehicle and the 30-minute travel time areas plus a 0.5-mile buffer via public transit for the census tract centroids in SPA6. For the sake of better visualization, Figure 28 below only shows the 30-minute travel areas via private vehicle and public transit for Census Tract 2184 (GEOID: 1400000US06037218400) as an example.

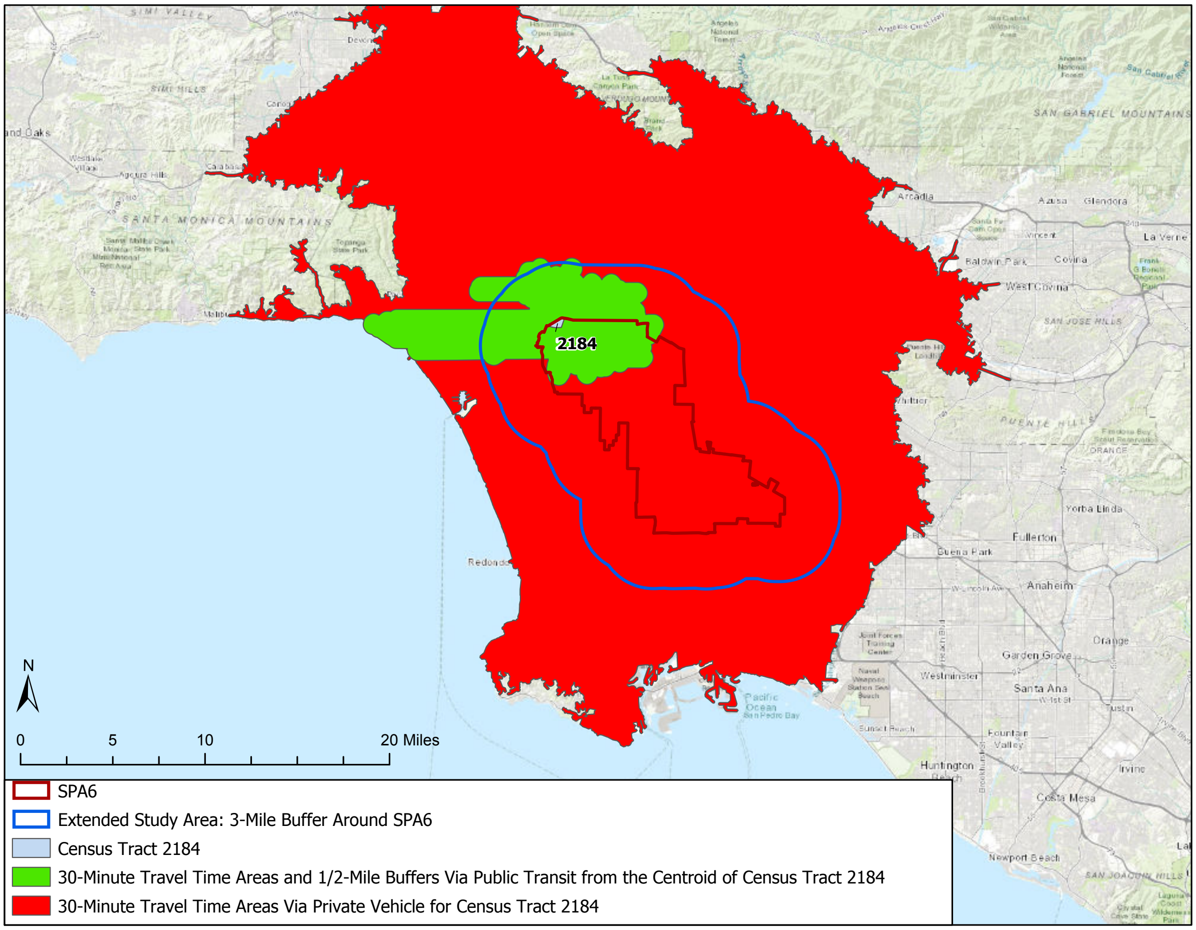

Figure 28. 30-Minute Travel Time Areas Via Private Vehicle and Public Transit for Census Tract 2184

The catchment area for a given census tract or primary care facility is defined as the intersection of its 30-minute travel time areas vis private vehicle and public transit. As discussed in Chapter 3, the first step of the 2SFCA analysis uses the catchment areas for existing low-cost primary care facilities and the final candidate sites to calculate the physician-to-population ratios for each low-cost primary care facility and the second step of the 2SFCA analysis uses the catchment areas for census tract centroids in SPA6 to sum up the physician-to-population ratio for each census tract as its accessibility score. Like the 30-minute travel time areas presented above, catchment areas of census tracts and primary care facilities also overlap to the point where visualizing all catchment areas in one map would be difficult. Therefore, Figure 29 below presents the catchment areas of Census Tract 2184 and final candidate site 12 as an example.

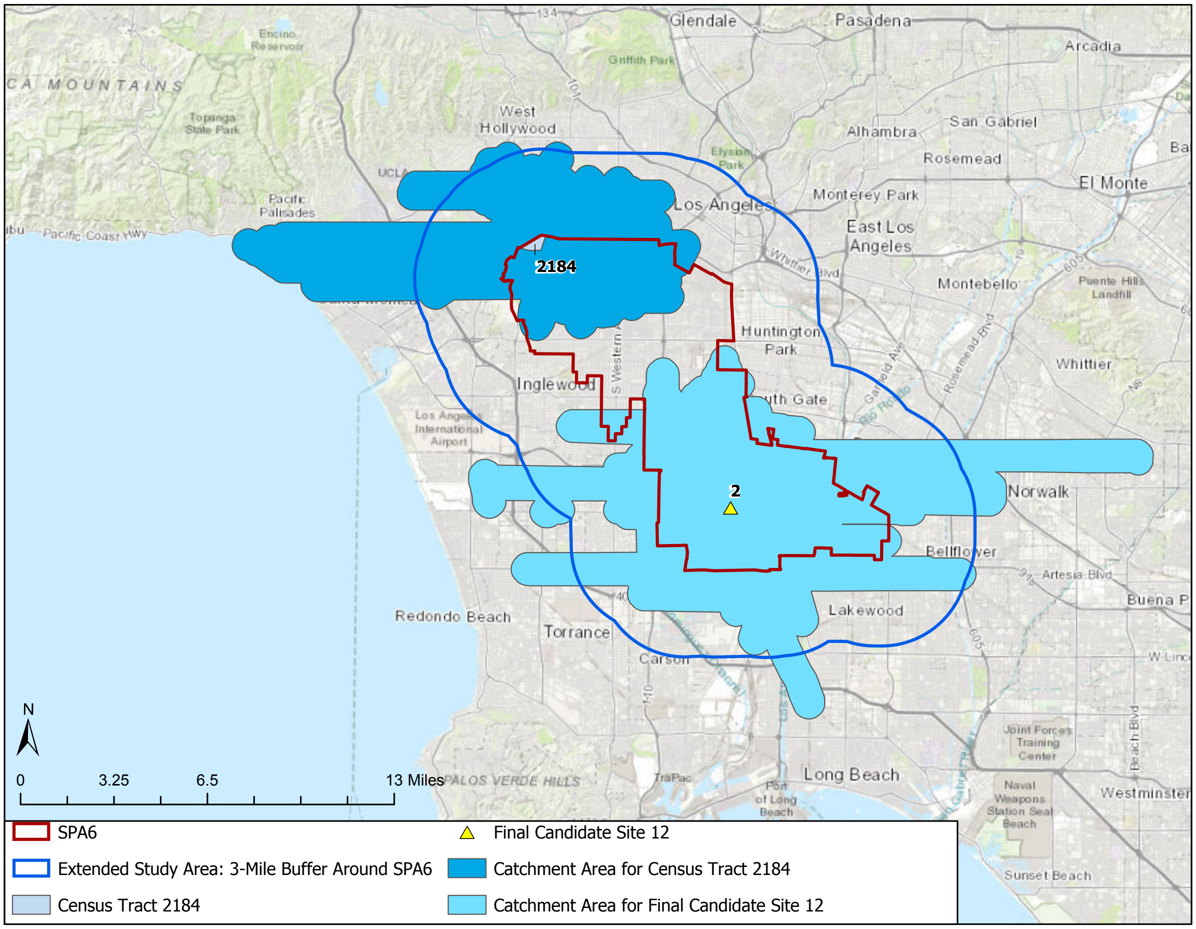

Figure 29. Catchment Areas for Census Tract 2184 and Final Candidate Site 12

4.3.2. Accessibility Scores

This sub-section presents the accessibility scores for census tracts in SPA6 with existing low-cost primary facilities as baseline and the accessibility scores for census tracts in SPA6 with the addition of each of the final candidate sites. It then compares the impacts of each candidate site on the overall low-cost primary care accessibility for low-income residents in SPA6.

As discussed in Chapter 3, the size of a candidate site determines its maximum service provision capacity because the need for space is a function of the number of physicians. Thus, this project estimated the maximum number of physicians working at a given final candidate site and the weekly service provision capacity of each final candidate site based on its size as presented in Table 6 below.

Table 6. Estimated Weekly Service Provision Capacity of the Final Candidate Sites

ID	Address	Size (Sq. Ft.)	Estimated Number of Physicians	Estimated Weekly Service Provision Capacity
1	1532 Firestone Blvd, Los Angeles, CA, 90001	4870.179248	2	80
2	4130 Florence Ave, Bell, CA, 90201	16323.30486	7	280
3	8001 Santa Fe Ave, Huntington Park, CA, 90255	21470.54491	9	360
4	2603 Grand Ave, Huntington Park, CA, 90255	8135.013437	2	120
5	2184 Firestone Blvd, Los Angeles, CA, 90002	3372.569554	1	40
6	2876 E Florence Ave, Huntington Park, CA, 90255	11653.9327	5	200
7	7721 Compton Ave, Los Angeles, CA, 90001	5539.405809	2	80
8	2182 Firestone Blvd, Los Angeles, CA, 90002	3141.668533	1	40
9	7718 Wilcox Ave, Cudahy, CA, 90201	22860.88452	10	400
10	1447 E 73rd St., Los Angeles, CA, 90001	3756.327908	1	40
11	1754 Firestone Blvd, Los Angeles, CA, 90001	4687.389735	1	40
12	13910 Wilmington Ave, Compton, CA, 90220	24312.85478	10	400
13	306 N. Central Ave, Compton, CA, 90220	8858.312761	3	120

In order to set a baseline to evaluate which final candidate site best increases low-cost primary care accessibility among low-income residents in SPA6, this project first calculated the low-cost primary care accessibility scores for the census tracts within SPA6 using only existing low-cost primary care facilities. With only existing low-cost primary care facilities, the mean accessibility score for the census tracts in SPA6 is 0.0210 with a standard deviation of 0.0172.

The sum of accessibility scores of all census tracts within SPA6 is 6.0909. Figure 30 below presents the low-cost primary care accessibility score for each census tract in SPA6 with currently existing low-cost primary care facilities.

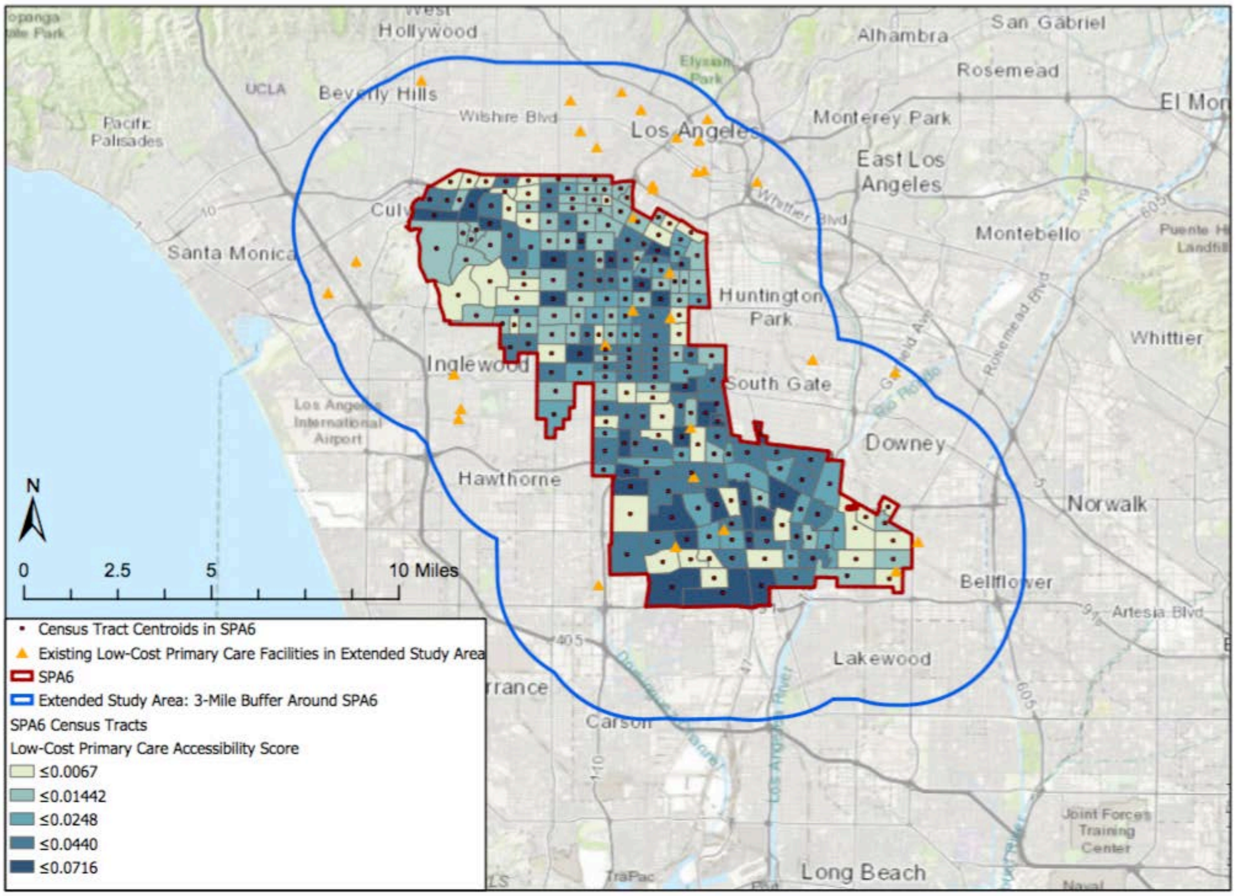

Figure 30. Current Low-Cost Primary Care Accessibility Scores by Census Tract in SPA6

After calculating the current low-cost primary care accessibility scores for census tracts in SPA6 as the baseline, this project calculated the low-cost primary care accessibility scores for census tracts in SPA6 with the addition of each of the 13 candidate sites. Table 7 below shows the mean, standard deviation, and sum of accessibility scores with the addition of each final candidate site as well as the baseline accessibility scores with only existing low-cost primary care facilities.

Table 7. Summary Statistics of the Low-Cost Primary Care Accessibility Scores

	Mean Accessibility Score	**Standard Deviation**	**Sum of Accessibility Scores of All Census Tracts within SPA6**
Existing Facilities Only	0.0210	0.0172	6.0909
Existing Facilities & Final Candidate Site 1	0.0212	0.0173	6.1578
Existing Facilities & Final Candidate Site 2	0.0215	0.0182	6.2261
Existing Facilities & Final Candidate Site 3	0.0220	0.0175	6.3787
Existing Facilities & Final Candidate Site 4	0.0213	0.0175	6.1755
Existing Facilities & Final Candidate Site 5	0.0211	0.0173	6.1137
Existing Facilities & Final Candidate Site 6	0.0217	0.0176	6.2840
Existing Facilities & Final Candidate Site 7	0.0212	0.0173	6.1484
Existing Facilities & Final Candidate Site 8	0.0211	0.0173	6.1141
Existing Facilities & Final Candidate Site 9	0.0215	0.0176	6.2457
Existing Facilities & Final Candidate Site 10	0.0211	0.0173	6.1157
Existing Facilities & Final Candidate Site 11	0.0211	0.0173	6.1213
Existing Facilities & Final Candidate site 12	0.0226	0.0174	6.5604
Existing Facilities & Final Candidate Site 13	0.0214	0.0172	6.1960

Table 7 above shows that final candidate site 12 increases the mean and sum of low-cost primary care accessibility scores for census tracts in SPA6 the most, followed by final candidate sites 3 and 6. Therefore, final candidate site 12 is the most suitable site for a new low-cost primary care facility to achieve the goal of improving low-cost primary care accessibility in for low-income populations in SPA6 if there are no other conditions, concerns, or restrictions. If financial resources for purchasing the land for the new low-cost primary care facility is limited, final candidate sites 13 and 4 are the most suitable parcels under 20,000 square feet and final candidate sites 1 and 7 are the most suitable parcels under 10,000 square feet.

Chapter 5 Discussion and Conclusion

This thesis provided both practical and methodological contributions to the GIS field and public health. In terms of practical contribution, this project provided site selection suggestions for a new low-cost primary care facility that could better increase affordable primary care accessibility for low-income residents in SPA6 than sites with similar size and cost. This is helpful for allocating resources more efficiently in order to provide more primary care to low-income residents in SPA6. Moreover, this project offered a list of final candidate sites with various sizes and land cost instead of one most suitable site, which provided flexible guidance to potential decision-makers. The first section discusses the methods used in this thesis and the results presented in the previous chapter. The second section analyzes the limitation of this project. Lastly, the third section discusses future research.

5.1. Discussion

This section discusses the methods used in this thesis and analyzes the suitable sites from the results in greater detail.

5.1.1. Overall Assessment of Methods and Analysis

The fuzzy overlay analysis assessed the 2,096 candidate sites based on four criteria, namely, distance to the closest existing low-cost primary care facility, distance to the closet public transit stop, land cost per square foot, and number of low-income residents within a 1-mile radius. This process generated final fuzzy membership values for each candidate sites, among which 13 candidate sites have a final membership value of 0.9 or above.

The fuzzy overlay analysis was successful because it evaluated candidate sites flexibly and holistically. The final fuzzy membership value reflected which sites best fit all four site selection criteria without allowing the high rating of one criterion to overly compensate for the low rating of another criterion. The fuzzy overlay analysis is also easily adjustable to suit different needs of future potential decision-makers' who are interested in other types of site selection. Firstly, potential decision-makers can use the result from the fuzzy overlay analysis itself as a reference for site selection if they do not require quantitative accessibility analysis because the fuzzy overlay analysis already provides a lot of decision-making support. Secondly, it is convenient to slightly alter the fuzzy membership assignment in the fuzzy overlay analysis to suit potential decision-makers' requirements. Moreover, potential decision-makers can choose to keep any number of sites from the fuzzy overlay analysis for further 2SFCA analysis based on their needs.

In this project, the 2SFCA method provided a quantitative and flexible assessment of low-cost primary care accessibility for the final candidate sites resulting from the fuzzy overlay analysis that not only accounted for both the supply and demand of low-cost primary care, but also avoided MAUP and border effects. Aiming to assess low-cost primary care accessibility in SPA6 more accurately and realistically, this project calculated catchment areas in the 2SFCA analysis with both travel time via private vehicle and public transit. As the maps in Chapter 4 indicate, the 30-minute travel time area via public transit with a 0.5-mile buffer is significantly smaller than the 30-minute travel time area via private vehicle. Considering the relatively low car ownership rate among low-income populations, it was crucial to incorporate travel time via public transit when defining the catchment areas for both candidate sites and population points. Due to the lack of available network dataset for public transit, this project created one using point and line features of public transit stops and routes in Los Angeles County. This project also added a 0.5-mile buffer, a reasonable walking distance, to the 30-minute travel time area via public transit to better reflect the reality.

The 2SFCA analysis generated accessibility scores of the 13 candidate sites with final fuzzy membership values above 0.9, providing a quantifiable criterion for potential decision-makers to select the most suitable site for a new low-cost primary care facility. The innovative use of the 2SFCA method to further evaluate the final candidate sites from the fuzzy overlay analysis provides insightful results. The fuzzy overlay analysis ranked candidate sites by how likely it is feasible and suitable to build a new low-cost primary care on them. All candidate sites with high final membership values could be suitable for this project. However, the fuzzy overlay analysis cannot provide a direct measurement of how these candidate sites contribute to the goal of this study, namely, increasing primary care accessibility for low-income residents in SPA6. Thus, this project adopted the 2SFCA method to build upon the fuzzy overlay analysis and to directly evaluate how much each final candidate site could contribute to the goal of this study. The results of the 2SFCA analysis indicate that the candidate sites with the highest final fuzzy membership value do not lead to the highest increase in low-cost primary care accessibility in SPA6. In fact, final candidate site 1, which has the highest final fuzzy membership value, ranks the 8th in improving the overall low-cost primary care accessibility among the 13 final candidate sites. Moreover, accessibility scores generated in the 2SFCA analysis can help entities that are interested in investing for a new low-cost primary care facility in SPA6 better present their case to the public and the local governments by intuitively demonstrating the positive impacts of the added affordable primary care provision. Furthermore, if potential decision-makers desire, the 2SFCA analysis can be easily expanded to more candidate sites or limited to fewer candidate sites. This provides the flexibility required in real-world decision making.

5.1.2. Discussion of the Final Results

This analysis shows that final candidate site 12 is the most suitable site for a new low-cost primary care facility that best increases primary care accessibility for low-income populations in SPA6. This sub-section presents detailed information on this site and discusses the potential of building a new low-cost primary care facility on the site.

Final candidate site 12 locates in the southern part of SPA6 surrounded by the West 139th Street, North Wilmington Avenue, North Kemp Avenue, and West Cressey Street. The size of this site is 24312.85 square feet or roughly 0.56 acre. It was last sold as vacant land in 2014 for $345,000 (Redfin.com), which matches the land value data used in this thesis. Figure 31 below presents a large-scale map for final candidate site 12 and an inset map that contextualizes its location in SPA6.

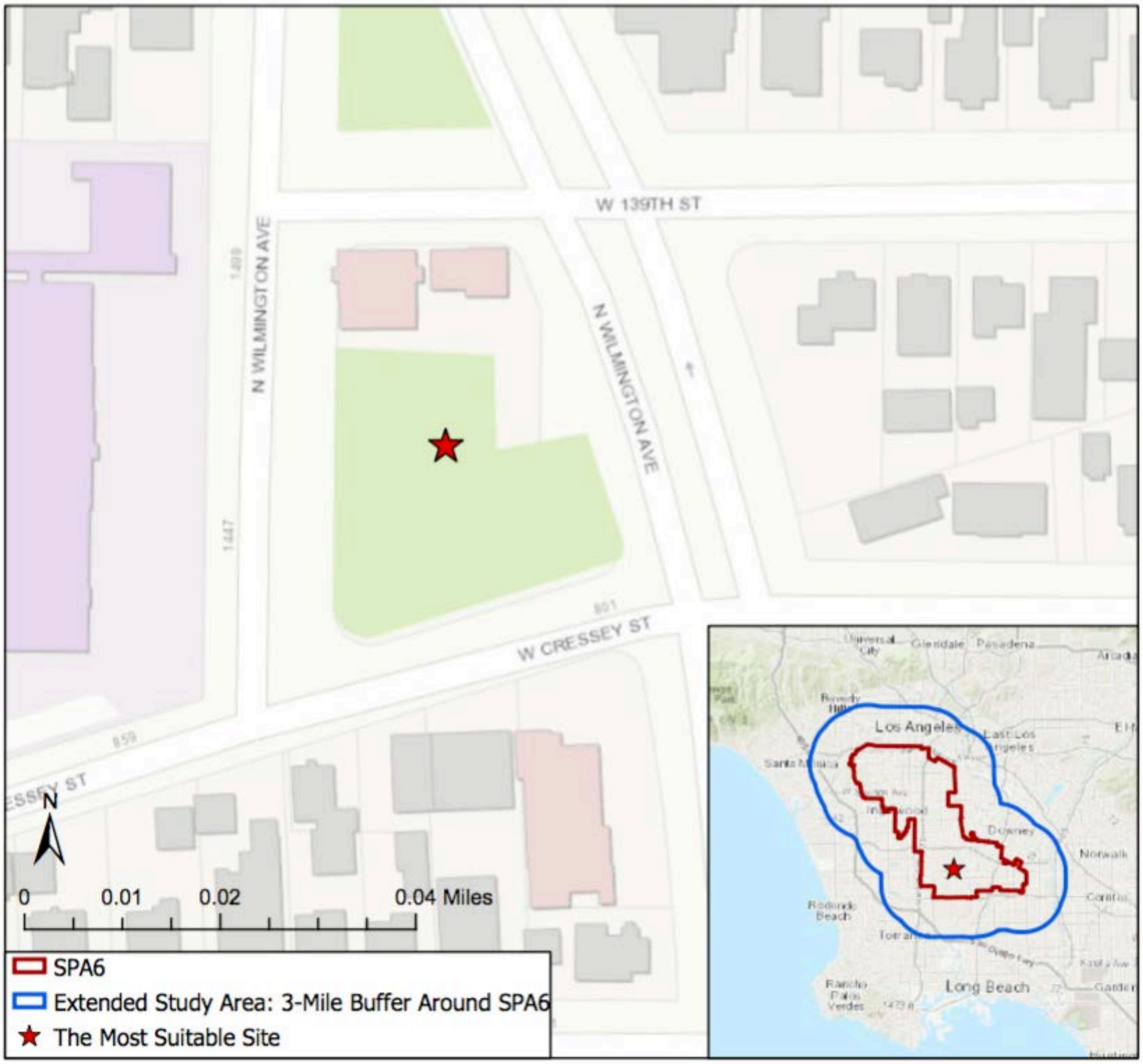

Figure 31. Large-scale Map of Final Candidate site 12

In order to get a better idea of final candidate site 12, Figure 32 below presents a satellite image of final candidate site 12 (circled in red) acquired from Google Maps and Figure 33 shows a photo of the site taken in 2014. These two figures show that final candidate site 12 is located in the middle of residential communities.

Figure 32. Satellite Image of Final Candidate site 12. Source: Google Maps. Accessed: March 22nd, 2019.

Figure 33. Photo of Final Candidate site 12. Source: Redfin.com. Accessed: March 22nd, 2019.

5.2. Limitations and Improvements

This section discusses the limitations of this project and potential improvements that could be made for similar future analyses. Most of the limitations of this project are due to data quality and data availability. In terms of data quality, this project strived to obtain the most accurate and up-to-date data available. However, due to data accessibility and availability issues, this project had to compromise and use the best-available data within in the scope of this thesis.

The first limitation of this project is that the demographic data regarding the distribution of low-income populations is aggregated on the census tract level. While this project strived to model low-income populations more accurately in the first step of the 2SFCA analysis by assuming even distribution of low-income populations across SPA6 instead of assuming all low-income populations concentrate on the census tract centroids as conventional research does, it still inevitably introduced errors to the analysis. Moreover, due to the lack of reliable data, this project did not consider the primary care need of homeless populations in the study area, which could potentially introduce inaccuracies to the results. While it is unlikely to completely solve this data availability problem, a potential improvement for this limitation could be made if future projects with more resources could acquire household-level or up-to-date census block demographic data.

The second limitation of this project is the road network dataset for public transit. Due to the lack of publicly available public transit road network dataset for the study area, this project created one using vector public transit route and stop data acquired from United States EPA Smart Location Database. This public transit road network dataset may not contain the most current or complete public transit information for the study area. Moreover, it also does not include data for accurately modeling traffic friction, wait time, or delay status. A potential improvement for this limitation could be made if future analyses could acquire a more detailed, accurate, and complete road network dataset for public transit in their study areas. If research resources are limited, a project that solely focuses on creating a road network dataset to model real-life public transit accurately and realistically would also have significant contribution to future studies.

The third limitation of this project is the land value data in the Parcel and Zoning Dataset. This project used land value per square foot as one of the criteria to evaluate the suitability of a candidate site. However, the land value data in the Parcel and Zoning Dataset is acquired from the Los Angeles County GIS Portal, which is based property tax data from 2015. Estimated land value for taxation purposes may not accurately reflect a property's market value and could be not up-to-date. However, since the Los Angeles County property tax assessor uses the same methodology to estimate the value of all properties, the estimation error is likely to be consistent for all candidate sites. Therefore, the relative land cost of a given candidate site in comparison to other candidate sites in the property tax data is still informative and accurate enough for this project to evaluate candidate sites. A potential improvement for this limitation is to use more accurate and up-to-date land cost data in the analysis. For instance, real estate listing websites such as Zillow.com and Redfin.com have algorithms developed to estimate the market price for properties based on a great number of publicly available data and user-submitted data. The results might be more accurate if future analyses have the resources to scrape these real estate listing websites and use their estimated land cost for the candidate sites in the site suitability analysis.

The fourth limitation of this project is the low-cost primary care provision capacity of each facility used in the 2SFCA analysis. Due to the lack of precise information that documents the actual primary care provided at each facility, this project estimates the service provision capacity based on the business hours and the number of providers at each facility. A potential improvement for this limitation could be made if similar future analyses had the authorization and budget to gather the actual service provision statistics of existing low-cost primary care facilities.

5.3. Future Research

This section discusses future research directions building upon this project. Firstly, this project can serve as a framework for similar future analyses. Potential decision-makers and GIS analysts can adopt the analytical methods and work flow used in this thesis and replicate the analysis using data from other study areas. A lot of communities, both domestic and international, desperately need more easily accessible affordable primary care. Future research replicating this project on other study areas could potentially help decision-makers to better allocate resources to benefit these communities. This type of future research could be particularly useful for local public health authorities such as Los Angeles Department of Health Services and nonprofit health care providers with government contracts. The analytical framework of this project can be tailored to the specific needs of the aforementioned entities, such as budget, facility size, specific candidate sites, and targeted clients, to help them select the most suitable site for a new primary care facility. If local public health authorities could provide more accurate data such as household-level demographic data and the actual workload of existing primary care facilities, the analytical framework from this thesis could also produce a more accurate analysis for the site selection.

Moreover, future research can also adapt the methods used in this project to address primary care provision issues for other disadvantaged groups, health care provision for patients with different health care needs, and other public service provision. For instance, future research that is interested in increasing affordable primary care for low-income senior citizens in a given study area can acquire demographic data to estimate the distribution of targeted service recipients and adjust the site selection criteria to account for the characteristics of senior citizens. In addition, future research can also adapt the analytical framework of this project to optimize the provision of other types of health care. Future research could collect relevant data on certain health care needs, especially the kind of health care needs that have clear geographic pattern. For instance, if local health authorities need to better allocate health care resources to serve residents with lead pollution-related diseases, future research could adapt the methods used in this project by including the spatial distribution of lead pollution and the targeted service recipients to address this new problem. Moreover, the methods used in this project can also be adapted and used in site selection analyses for other public service provision. For instance, future research can employ the same Fuzzy Overlay Analysis and 2SFCA methods to select a suitable site for a new soup kitchen or a low-budget food store to increase food accessibility for low-income populations.

Furthermore, future research can build upon this project and improve the modeling of travel time via public transit. Future research could build more realistic and accurate road network datasets using public transit routes, stops, wait time, delay and other data for more study areas. If resources permit, future research could even use real time public transit data to analyze travel time and catchment areas.

5.4. Conclusion

This thesis provides site selection suggestions for a new low-cost primary care facility that best improves the affordable primary care accessibility for low-income populations in SPA6 using fuzzy overlay analysis and 2SFCA analysis. The results of this project could help private or public entities that are interested in providing low-cost primary care in SPA6 better allocate their resources so that low-income residents could benefit more from the investment.

In terms of contribution, this project analyzes site suitability while taking into consideration the economic characteristics of the targeted service recipients and assesses low-cost primary care accessibility quantitatively. This thesis accounts for the relatively low car ownership rate among low-income populations and calculates service area with travel time via both private vehicle and public transit in order to more accurate model the suitability and geographical accessibility of candidate sites. Moreover, this thesis quantitatively assesses the impact on low-cost primary care accessibility in SPA6 of each final candidate sites using the 2SFCA method, providing more accurate information for potential decision-makers.

This thesis offers both practical guidance for decision-makers to address the real-world problem in SPA6 and an analytical framework for GIS analysts to solve similar problems elsewhere.

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