
Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region

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Abstract. This article synthesizes two GIS-based accessibility measures into one framework, and applies the methods to examining spatial accessibility to primary health care in the Chicago ten-county region. The floating catchment area (FCA) method defines the service area of physicians by a threshold travel time while accounting for the availability of physicians by their surrounded demands. The gravity-based method considers a nearby physician more accessible than a remote one and discounts a physician's availability by a gravity-based potential. The former is a special case of the latter. Based on the 2000 Census and primary care physician data, this research assesses the variation of spatial accessibility to primary care in the Chicago region, and analyzes the sensitivity of results by experimenting with ranges of threshold travel times in the FCA method and travel friction coefficients in the gravity model. The methods may be used to help the US Department of Health and Human Services and state health departments improve designation of Health Professional Shortage Areas.

Introduction

Accessibility refers to the relative ease by which the locations of activities, such as work, shopping, and health care, can be reached from a given location (BTS, 1997, page 173). Access to health care varies across space because access to health care is affected by where health professionals locate (supply) and where people reside (demand) and neither health professionals nor population is uniformly distributed. Physician shortage has been especially pronounced in rural areas and impoverished urban communities (COGME, 2000; Rosenblatt and Lishner, 1991). The US federal government spends about \$1 billion a year on programs designed to alleviate access problems, including awarding financial assistance to providers and assigning National Health Service Corps personnel to serve designated shortage areas (GAO, 1995). Any effective remedies begin with reliable measures of accessibility to health care.

Access to health care may be classified according to two dichotomous dimensions (potential versus revealed, and spatial versus aspatial) into four categories, such as: potential spatial access, potential aspatial access, revealed spatial access, and revealed aspatial access (Khan, 1992). *Revealed accessibility* focuses on actual use of health care services, whereas *potential accessibility* signifies the probable entry into the health care system, but does not ensure the automatic utilization of the offered services (Joseph and Phillips, 1984; Khan, 1992; Phillips, 1990; Thouez et al, 1988). *Spatial access* emphasizes the importance of the spatial/distance variable (as a barrier or a facilitator), whereas the *aspatial access* stresses nongeographic barriers or facilitators, such as social class, income, ethnicity, age, sex, etc (Joseph and Phillips, 1984; Khan, 1992; Meade and Earickson, 2000, page 383–392). This paper focuses primarily on measuring *potential spatial accessibility*. The measures of potential spatial accessibility include regional availability and regional accessibility (Joseph and Phillips, 1984). The *regional availability* approach is simpler and measures distribution of supply versus demand within a region, often expressed as a population-to-practitioner ratio (or its variation) within that region. The *regional accessibility* approach considers such

potential for complex interaction between supply and demand located in different regions and thus is more complex and requires more data (Joseph and Phillips, 1984).

The US Department of Health and Human Services (DHHS) uses two main systems for identifying shortage areas (GAO, 1995; Lee, 1991). One designates Health Professional Shortage Areas (HPSAs), the other Medically Underserved Areas or Populations (MUAs/MUPs). Both systems use the ratio of population to full-time-equivalent (FTE) primary care physicians within a 'rational service area' as a basic indicator (for example, 3500:1 in HPSA designations), and thus are primarily regional availability measures of potential spatial access with some aspatial elements. For example, the HPSAs can include population groups (for example, low-income or minority groups) and MUAs/MUPs consider aspatial factors, such as infant mortality rate, income level, and age. A rational service area may be (a) a whole county or groups of contiguous counties, (b) a portion of a county, or an area made up of portions of more than one county, (c) established neighborhoods and communities. For details, see guidelines at <http://bphc.hrsa.gov/dsd> (last accessed 3 December 2002). This paper will focus on spatial factors. Our ongoing research will address aspatial issues, and results will be reported in the near future.

The problems of the regional availability measures are that (1) they cannot reveal the detailed spatial variations within those large rational service areas (such as counties or group of counties) and (2) they carry the assumption that the boundaries are impermeable, that is, the actual interaction across boundaries is not adequately accounted for (Joseph and Phillips, 1984). In other words, access to health care depends, not only upon the supply of resources in a community, but also upon the supply of such resources in neighboring communities (GAO, 1995; Wing and Reynolds, 1988) and the distance and ease of travel among them (Kleinman and Makuc, 1983, page 543). The severity of the two problems also changes with the scale (that is, level of aggregation). The higher the aggregation level of rational service areas (that is, the larger the areal unit), the more serious the internal variation problem is, but the less serious the permeability problem is. The reverse is true for lower aggregation level. The two cannot be easily reconciled within the framework of regional availability measures.

Recent revisions of criteria for designating HPSAs and MUAs/MUPs intend to address the problems by (1) using geographic units smaller than counties as rational service areas (for example, minor civil divisions, census tracts), and (2) considering the impact of neighboring areas. For example, the third criterion in defining HPSAs specifies that medical resources in contiguous areas need to be "overutilized, excessively distant, or inaccessible". Implementing this criterion requires incorporating regional accessibility measures. In other words, it calls for an integration of regional availability (demand-to-supply ratio) and regional accessibility (interaction between demand and supply) measures.

The increasing abundance of digital data (for example, population data, street and road network, physician database) and advancement of GIS technology now make it possible to identify distributions of physicians and population at finer spatial resolutions (Cromley and McLafferty, 2002; Kohli et al, 1995; Love and Lindquist, 1995; Lovett et al, 2002; Mukuc et al, 1991; Parker and Campbell, 1998). In the meantime, the literature of accessibility measures has grown in a variety of fields (see related reviews in the following sections where methods are discussed). Several methods consider the effects of neighboring communities while accounting for availability of health care providers. Among others, the following two are most noticeable:

- (1) the *spatial decomposition method* by Radke and Mu (2000), and
- (2) the *gravity-based method* by Weibull (1976) and applied to health care access by Joseph and Bantock (1982).

This paper builds upon prior research, and makes contributions in the following ways:

(a) It proves that the spatial decomposition method (referred to as the *two-step floating catchment area method* in this paper for reasons explained in a later section) is merely a special case of the gravity-based method, and thus synthesizes them into one framework. This reinforces the rationale of the two methods, which capture the same essence of accessibility measures.

(b) Unlike most prior work using straightline distances, this research uses travel times to measure the spatial barrier between residents and physicians. In addition, the travel times are estimated systematically and consistently in a GIS environment, which have been either approximated by distances or estimated manually on a case-by-case basis (unpublished DHHS training manual).

(c) The methods are applied to measuring health care accessibility using smaller geographic units (that is, physicians in ZIP-code areas and population in census tracts), and therefore more details of accessibility variations can be revealed.

Specifically, this paper examines spatial accessibility to primary health care in the Chicago ten-county region in 2000, with a focus on methodology issues. Results may be used to help the DHHS and state health departments design a better system for designation of areas of physician shortage.

The study area, data sources, and travel time estimation

The ten Illinois counties in the Chicago CMSA (Consolidated Metropolitan Statistical Area) are chosen as the study area for this paper. See figure 1 (over). The area represents a small portion of the State of Illinois (to be studied in a larger project) so that local variations may be displayed in reasonable detail, yet this densely populated area accounted for two thirds of population in Illinois in 2000. Both urban and rural areas are represented in the region because some peripheral counties are mostly rural. In order to account for 'edge effects', a fifteen-mile buffer zone (approximately 30 minutes travel time) is identified near the borders of the study area (except for the shorelines of Lake Michigan on the east). Accessibility measures in this buffer zone need to be interpreted with caution because residents may seek health care outside the study area.

The population data were extracted from the 2000 Census Summary File 1 (US Bureau of Census, 2001a), and the corresponding spatial coverages of census tracts and blocks were generated from the 2000 Census TIGER/Line files (US Bureau of Census, 2001b). As the population is seldom distributed homogeneously within a census tract, the population-weighted centroid instead of the simple geographic centroid of a census tract represents the location of population more accurately (Hwang and Rollow, 2000). The population centroid of a tract may be distant from its geographic centroid, particularly in rural or peripheral suburban areas where tracts are large and population tends to concentrate in limited space. Weighted centroids are computed based on block-level population data, such as

$$x_c = \frac{\sum_{i=1}^{n_c} p_i x_i}{\sum_{i=1}^{n_c} p_i} , \quad (1)$$

$$y_c = \frac{\sum_{i=1}^{n_c} p_i y_i}{\sum_{i=1}^{n_c} p_i} , \quad (2)$$

where x_c and y_c are the x and y coordinates of the weighted centroid of a census tract, c ; x_i and y_i are the x and y coordinates of the i th block centroid within that census tract; p_i is the population at the i th census block within that census tract;

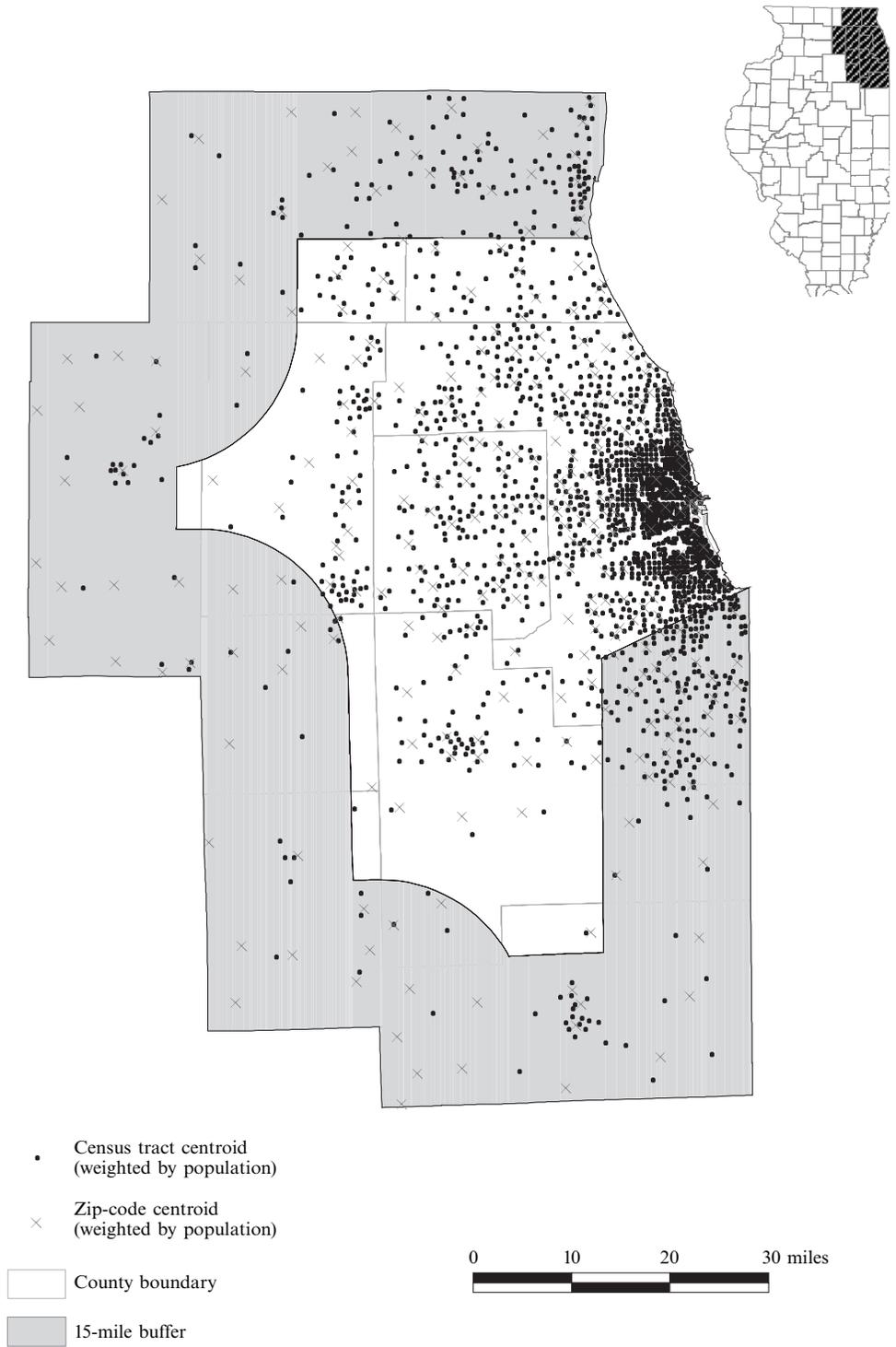


Figure 1. The Chicago 10-county region.

and n_c is the total number of blocks within that census tract. The census tract is chosen as the analysis unit for population distribution, because it is the lowest areal unit used in the current practice of shortage-area designation, and the number of tracts is computationally manageable for travel-time estimation and accessibility modeling. In the study area, there were 1901 census tracts with a total population of 8376 604 in 2000 (see figure 1).

The primary care physician data of Illinois in 2000 were purchased from the Physician Master File of the American Medical Association (AMA) via Medical Marketing Service Inc. Primary care physicians include family physicians, general practitioners, general internists, general pediatricians, and some obstetrician–gynecologists (Cooper, 1994). This case study focuses on primary care physicians because these physicians are an integral component of a rational and efficient health delivery system and they are critical for the success of preventive care (Lee, 1995). Most of the HPSAs designated by the DHHS are also for primary medical cares (others are mental health and dental HPSAs). The methodology presented here can be easily adapted to identify shortage areas of other health care specialties, and at state and national levels.

Ideally, the physician locations should be geocoded by their street addresses with GIS software, a process of converting the address information to x and y coordinates of a point on the map by matching address name and interpolating the address range to those stored in a digital map (for example, TIGER/Line file). However, a significant number of records in the Physician Master File have only PO box addresses, which are not feasible for geocoding. This study simply used the centroid of zip code of a physician's office address to represent the physician's location. Only when the office addresses were not available, were the zip codes of preferred addresses used (such cases account for 18.5% of the records, which may or may not be office addresses). As physicians often choose to practice at populated places, population-weighted centroids instead of the simple geographic centroids of zip-code areas were used, and computed similarly to census tract centroids as in equations (1) and (2). The population of each block whose centroid falls within a zip-code area was used as the weight to calculate the population-weighted centroid for that zip code. We are aware of the problems associated with using zip-code data because zip codes may be totally unrelated to health care or demographic data. For example, some 'point zips' are for small rural post offices that have only a set of boxes for mail pickup. Many in urban areas are for office buildings or government subdivisions that are unrelated to either physician or potential patients (Wing and Reynolds, 1988). However, the zip code represents a finer resolution than the county and has been used extensively in health research (for example, Knapp and Harwick, 2000; Ng et al, 1993; Parker and Campbell, 1998). The AMA physician data do not identify how much percentage of time each physician serves at one location among multiple offices, and thus do not enable us to obtain the number of FTE physicians. Converting the FTE physicians requires extensive surveys and fieldwork (personal communication with Mary Ring and Jerry Partlow, Center for Rural Health, Illinois Department of Public Health, 22 August 2002), which are beyond the scope of this project. The focus of the paper is to demonstrate the methodology. Better physician information will certainly improve the result. There were 325 zip codes with 19202 primary physicians in the study area in 2000 (see figure 1). Table A1 in the appendix also provides total numbers of primary care physicians and population, and their ratios in all ten counties in the study area.

The methods of accessibility measures discussed in the next two sections utilize travel time between any pair of population and physician locations. Road networks for travel-time estimation were also extracted from the 2000 Census TIGER/Line files. Assuming people taking the fastest path, we used the Arc/Info network analysis

module to derive the shortest travel time between any two locations. Travel speeds may also be dictated by traffic signals and preset speed limits [often reduced in business districts or high residential density areas (see IDOT, 1977)]. For planning purposes, people can be assumed to travel at the speed limit, which is used as the impedance value for each road segment in the network quickest path computation. After a careful examination of the speed-limit maps maintained by the Illinois Department of Transportation,⁽¹⁾ we developed several rules to approximate travel speeds based on the population density pattern (see table A2 and figure A1 in the appendix). See Wang (2003) for more details of estimating travel times.

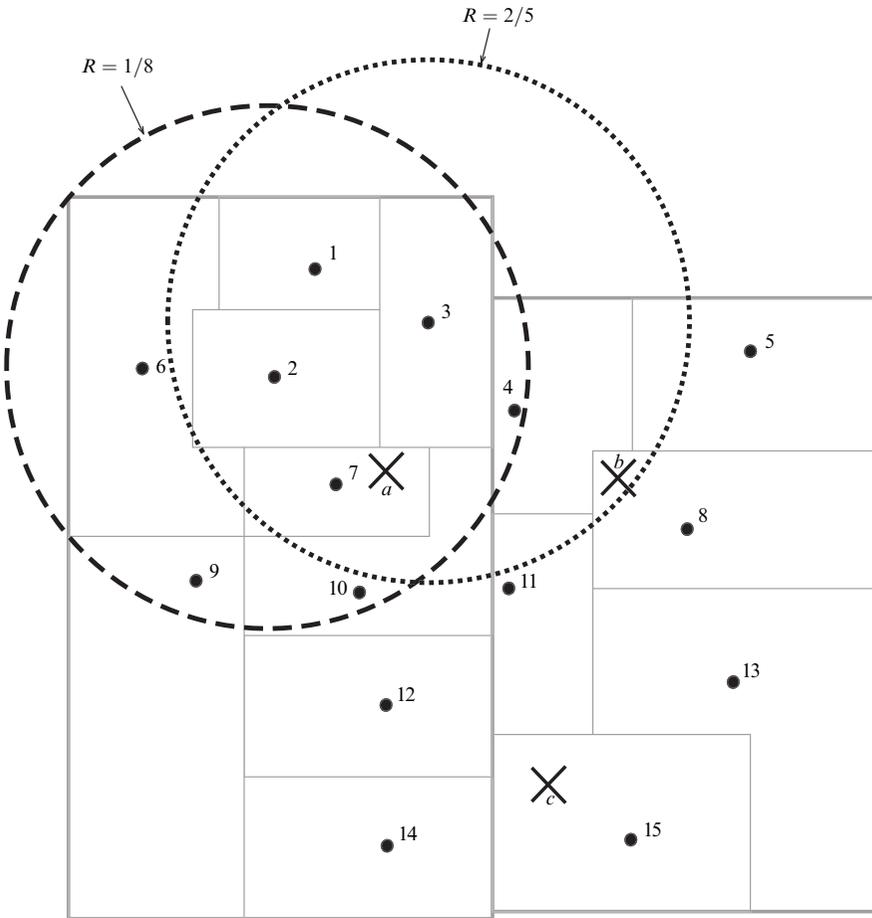
The evolution of floating catchment area methods

Given the broad interests in accessibility measures, several approaches have been developed in various applications. Earlier versions of the floating catchment area (FCA) method were used in assessing job accessibility (for example, Peng, 1997; Wang, 2000). This method somewhat resembles kernel estimation (for example, Bailey and Gatrell, 1995), in which a 'window' (kernel) is moved across a study area, and the density of events within the window is used to represent the density at the center of the window. In estimating the density, one may use a gravity model to weigh events by the inverse of distances from the center. Figure 2 uses an example to illustrate the method. For simplicity, assume that each census tract has only one person residing at its centroid and each physician location has only one physician practising there. Also assume that a threshold travel distance for primary health care is 15 miles. A 15-mile circle around the centroid of residential location 2 defines its catchment area [Peng (1997) used a square to define a catchment area]. Accessibility in a census tract is defined as the physician-to-population ratio within its catchment area. For instance, there are one physician (that is, a) and eight residents within the catchment area, and thus accessibility to physicians for tract 2 is their ratio $1/8$. The circle floats from one centroid to another while its radius remains the same. Similarly, there are two physicians (a and b) and five residents within the 15-mile catchment area of tract 3, and thus the accessibility for tract 3 is their ratio, $2/5$. The underlying assumption is that services that fall within the catchment area will be fully available to residents within that catchment area. This assumption is obviously faulty. For example, the distance between a physician and a resident within the catchment area may exceed the threshold travel time (for example, distance between 1 and b is greater than the radius of the catchment of tract 3 in figure 2). Furthermore, the physician at b is within the catchment of tract 3, but may not be fully available to serve residents within the catchment because he or she will also serve nearby (but outside-the-catchment) residents at 5, 8, or 11. Wang and Minor (2002) used travel times instead of straight-line distances to define the catchment area, but the fallacy remains.

In addressing the issues, Radke and Mu (2000) developed the spatial decomposition method to measure access to social services. The method computes the ratio of suppliers to residents within a service area centered at a supplier's location and sums up the ratios for residents living in areas where different providers' services overlap. Like the earlier versions of FCA approach, they used straight-line distances. In their study, analysis areas may be split by an overlaying circle, and service areas are a set of *decomposed* areas. In this research we use centroids to represent whole census tracts or zip-code areas for simplicity, and thus the process does not involve decomposition

⁽¹⁾ According to personal contacts with engineers in the Illinois Department of Transportation, data for speed-limit settings are cumbersome, and still maintained and updated manually on maps. Digitizing the official speed limits is beyond the scope of this project. We are currently exploring other approaches for improving travel-time estimates.

of polygons as described in Radke and Mu (2000). The method is referred to hereafter as the two-step FCA method to reflect its connection to the tradition of FCA methods. The method uses travel times, and is implemented in two steps. The following procedures are organized in a way for easy interpretation using notation consistent with the gravity-based method to be introduced in the next section.



- 15-mile catchment area for tract 2
- 15-mile catchment area for tract 3
- ¹ Census tract centroid and identifier
- ⊗_a Physician location and identifier
- County boundary
- Census tract boundary

Figure 2. An earlier version of the floating catchment area (FCA) method.

Step 1. For each physician location j , search all population locations (k) that are within a threshold travel time (d_0) from location j (that is, catchment area j), and compute the physician-to-population ratio, R_j , within the catchment area:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k}, \quad (3)$$

where P_k is the population of tract k whose centroid falls within the catchment (that is, $d_{kj} \leq d_0$), S_j is the number of physicians at location j , and d_{kj} is the travel time between k and j .

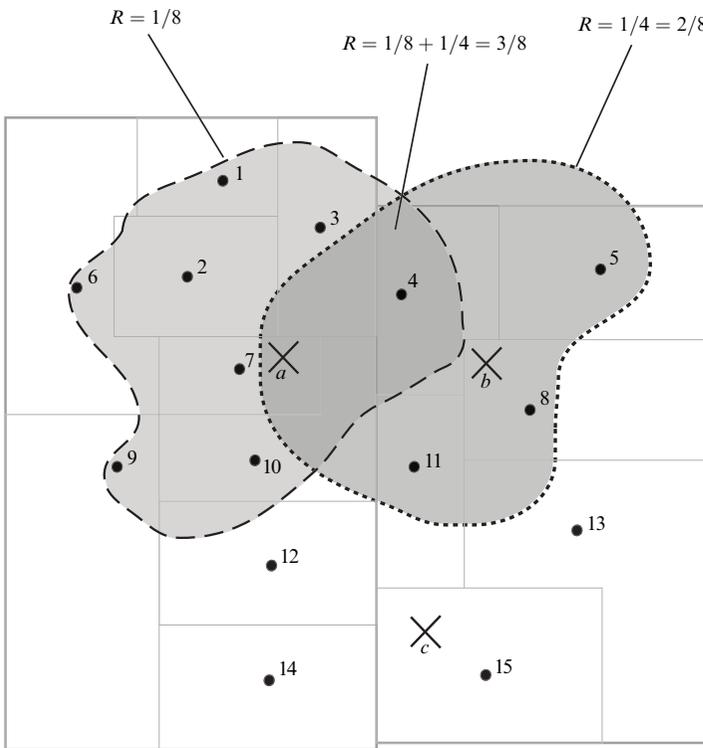
Step 2. For each population location i , search all physician locations (j) that are within the threshold travel time (d_0) from location i (that is, catchment area i), and sum up the physician-to-population ratios, R_j , at these locations:

$$A_i^F = \sum_{j \in \{d_{ij} \leq d_0\}} R_j = \sum_{j \in \{d_{ij} \leq d_0\}} \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k}, \quad (4)$$

where A_i^F represents the accessibility at resident location i based on the two-step FCA method, R_j is the physician-to-population ratio at physician location j whose centroid falls within the catchment centered at i (that is, $d_{ij} \leq d_0$), and d_{ij} is the travel time between i and j . A larger value of A_i^F indicates a better accessibility at a location. The first step corresponds to the assigning of an initial ratio to each service area centered at physician locations, and the second step corresponds to summing up the initial ratios in the overlapped service areas (where residents have access to multiple physician locations). This is similar, in effect, to decomposing the FCA in Radke and Mu (2000). In implementation, a matrix of travel times between any pair of physician location and population location (d_{ij} or d_{kj}) is computed once and accessed twice.

Figure 3 uses an example to illustrate this two-step FCA method, assuming the same distributions of population and physicians as in figure 2 and a threshold travel time of 30 minutes. The different shades of the polygons represent different physician-to-population ratios. The catchment area for physician a has one physician and eight residents, and thus carries a physician-to-population ratio of $1/8$. Similarly, the physician to population ratio for catchment b is $1/4$. Residents at 1, 2, 3, 6, 7, 9, and 10 have access to physician a only and the ratio for them remains $1/8$; and residents at 5, 8, and 11 have access to physician b only and thus a ratio of $1/4$. However, the resident at 4 is located in an area overlapped by catchment areas a and b , and has access to both physicians a and b , and therefore enjoys a better accessibility (that is, a higher ratio $1/8 + 1/4 = 3/8$). This overlapped area is identified in the second step, which finds that physicians a and b are both within a 30-minute catchment area of resident 4 (not shown in figure 3).

Note that the catchment drawn in the first step is centered at a physician location, and thus the travel time between the physician and any person within the catchment does not exceed the threshold travel time. The catchment drawn in the second step is centered at a resident location, and residents may visit physicians within the catchment and only these physicians contribute to the physician-to-population ratios for those residents. The method overcomes the fallacy in earlier FCA methods. Note that equation (4) is basically a ratio of supply to demand, with only selected physicians and residents entering the numerator and denominator. The two-step FCA method considers interaction between patients and physicians across administrative borders based on travel times, and computes an accessibility measure that varies from one



- 30-minute catchment area for physician *a*
- 30-minute catchment area for physician *b*
- ¹ Census tract centroid and identifier
- ⊗_{*a*} Physician location and identifier
- County boundary
- Census tract boundary

Figure 3. The two-step floating catchment area (FCA) method.

tract to another. However, it draws an artificial line (say, 30 minutes) between an accessible and an inaccessible physician. Physicians within that range are counted equally regardless of the actual travel time (for example, 5 minutes versus 25 minutes). Similarly, all physicians beyond that range are defined as inaccessible, regardless of any differences in travel time.

The gravity-based method and a synthesis

We start with a simple gravity model to illustrate the concept. Hansen (1959) proposed the following model for accessibility (A_i^H) at location *i*:

$$A_i^H = \sum_{j=1}^n S_j d_{ij}^{-\beta} , \tag{5}$$

where S_j is the number of physicians at location *j*, d_{ij} is the travel time between population location *i* and physician location *j*, β is the travel-friction coefficient, and

n is the total number of physician locations. In the model, a physician nearby is considered more accessible than a remote one, and thus weighted higher. A similar version is also discussed by Cromley and McLafferty (2002, pages 233–258).

One limitation of equation (5) is that it considers only the ‘supply side’ of health care (physicians), but not the ‘demand side’ (that is, competition for available physicians among residents). Weibull (1976) improved the measurement by accounting for competition for services among residents. Joseph and Bantock (1982) applied the method to assess health care accessibility. Similar approaches have been used for evaluating job accessibility (Shen, 1998; Wang and Minor, 2002). The gravity-based accessibility measure at location i can be written as

$$A_i^G = \sum_{j=1}^n \frac{S_j d_{ij}^{-\beta}}{V_j}, \quad (6)$$

where

$$V_j = \sum_{k=1}^m P_k d_{kj}^{-\beta},$$

A_i^G is the gravity-based index of accessibility, where n and m are the total numbers of physician and population locations, respectively, and the other variables are the same as in equation (4). Compared with the primitive accessibility measure A_i^H , A_i^G discounts the availability of a physician by the service-competition intensity at that location, V_j , measured by its population potential. A larger A_i^G implies better accessibility.

This accessibility index may be interpreted like the one defined by the two-step FCA method. It may be considered as the ratio of supply (physicians S) to demand (population P), both of which are weighted by negative power of travel times. Indeed, the weighted average of accessibility in all locations (using population as weight) is equal to the physician-to-population ratio in the whole study area (for a proof, see Shen, 1998). This property also applies to the two-step FCA accessibility defined by equation (4). A careful examination of the two methods further reveals that the two-step FCA method is merely a special case of the gravity-based accessibility method.

Note that the improved FCA method treats travel-time impedance as a dichotomous measure, that is, any travel time within a threshold is equally accessible and any travel time beyond the threshold is equally inaccessible. Using d_0 as the threshold travel time, we may recode:

- (a) d_{ij} (or d_{kj}) = ∞ , if d_{ij} (or d_{kj}) > d_0 ; and
 (b) d_{ij} (or d_{kj}) = 1, if d_{ij} (or d_{kj}) \leq d_0 .

For any β in equation (6), we have

- (a) $d_{ij}^{-\beta}$ (or $d_{kj}^{-\beta}$) = 0, when d_{ij} (or d_{kj}) = ∞ ; and
 (b) $d_{ij}^{-\beta}$ (or $d_{kj}^{-\beta}$) = 1, when d_{ij} (or d_{kj}) = 1.

In case (a), S_j or P_k are excluded by being multiplied by zero; and in case (b), S_j or P_k are included by being multiplied by one. Therefore, equation (6) is regressed to equation (4), and thus the two-step FCA measure is just a special case of the gravity-based measure. Considering that the two methods have been developed in different fields for a variety of applications, this proof reinforces their rationale for capturing the essence of accessibility measures.

The case study and sensitivity analysis

Applying the two GIS-based accessibility measures to the Chicago ten-county region requires definitions of two key parameters: the travel-time threshold d_0 in the two-step FCA method and the travel-friction coefficient β in the gravity-based method.⁽²⁾ Drawn from prior studies in the literature, reasonable ranges for the two parameters are defined, and sensitivity analysis is conducted by experimenting with various values within the ranges. Lee (1991) suggested using a threshold travel time of 30 minutes for primary road conditions. The same threshold is used for defining rational service area and determining whether contiguous resources are excessively distant in the guidelines for HPSA designation (<http://bphc.hrsa.gov/dsd>). In this study, seven thresholds ranging between 20 and 50 minutes (with an increment of 5 minutes) have been tested in the two-step FCA method. In a previous study of job-commuting patterns in the same area, the travel-friction coefficient β was derived as 1.85 (Wang, 2000). This study has tested seven values of β ranging from 1.0 to 2.2 (with an increment of 0.2).

Table 1 presents the standard deviations for the two accessibility measures with different choices of parameters. Note that the weighted mean of any accessibility measure is always equal to the physician-to-population ratio in the whole study area (that is, 0.002292), and therefore the mean values of accessibility are omitted from table 1. Several observations can be made from table 1:

- (1) By the two-step FCA method, a larger threshold travel time leads to a smaller variance of accessibility scores. In other words, a larger threshold travel time generates stronger spatial smoothing, and reduces variability of accessibility across space (also see Fotheringham et al, 2000, page 46).
- (2) Among the accessibility measures obtained by the gravity-based method, larger variances of accessibility scores are associated with higher values of travel-friction coefficient β . Indeed, a larger β -value implies that residents are more discouraged by long travel times in seeking primary care, and thus have a higher tendency to settle for service providers in nearby locations.
- (3) The effect of a larger threshold travel time in the two-step FCA method is equivalent to that of a smaller travel-friction coefficient in the gravity-based method. People would travel farther to see a physician when travel friction is less significant. For instance, the variance in the case when $d_0 = 50$ minutes (in the two-step FCA method) is similar to the variance in the case when $\beta = 1.8$ (in the gravity-based method). Note that the former considers only physicians accessible within a threshold travel time

Table 1. Sensitivity analysis of accessibility measures.

Two-step floating catchment area method		Gravity-based method	
threshold travel time d_0	standard deviation of A_i^F	travel-friction coefficient β	standard deviation of A_i^G
20	0.002570	2.2	0.000999
25	0.001550	2.0	0.000934
30	0.001240	1.8	0.000863
35	0.001110	1.6	0.000787
40	0.001040	1.4	0.000705
45	0.000953	1.2	0.000619
50	0.000873	1.0	0.000527

⁽²⁾One may suggest using actual data of primary care physician visits to determine the two parameters. This could be problematic. As pointed out by a reviewer, such estimates are likely to be confounded with the existing distribution of physicians in the region instead of representing the true travel frictions.

whereas the latter considers physicians at any locations accessible by residents, though to different degrees.

(4) Compared with the two-step FCA method, the gravity-based method tends to give higher accessibility scores to areas with low accessibility. See figure 4 for a comparison between the two methods, where their accessibility scores have similar variances and certainly equal weighted means. This indicates that the gravity-based method could conceal local pockets of poor accessibility.

Using a threshold time of 30 minutes (as suggested by Lee, 1991), figure 5 shows the spatial variation of primary care accessibility in the Chicago ten-county region by the two-step FCA method. The grouping of accessibility classes was based on natural breaks in ArcGIS, which identifies breakpoints between classes using a statistical formula that minimizes the sum of the variance within each of the classes. For easy comparison, we added breaks at 3500 (DHHS standard) and 436 (average in the region). Because of edge effects, a 15-mile buffer zone (approximately 30 minutes travel time) near the borders of the study area is masked out. Three areas enjoy the best accessibility: one in downtown Chicago (commonly-known as the 'Loop') where some hospitals are located but with fewer residents, one in the north suburb or Lincolnwood–Skokie area where major research hospitals are located, and one in the west suburb or Elmhurst–Oak Brook area with several regional hospitals. All three areas are on major interstate highway intersections with easy transportation access. Also note some local pockets of relatively poor accessibility in the City of Chicago's south side and areas around the Midway Airport. In general, rural areas suffer from poor accessibility.

As the focus of the paper is on potential spatial accessibility, important aspatial factors are not considered here. Thus the results from this paper are not directly comparable with those areas of physician shortage designated by the DHHS. See figure A2 in the appendix for the latest existing primary care physician shortage designated in the study area as of 23 May 2001 (DHHS, 2002). Most of the shortage areas were defined because of aspatial factors, such as income, ethnicity, and age groups.

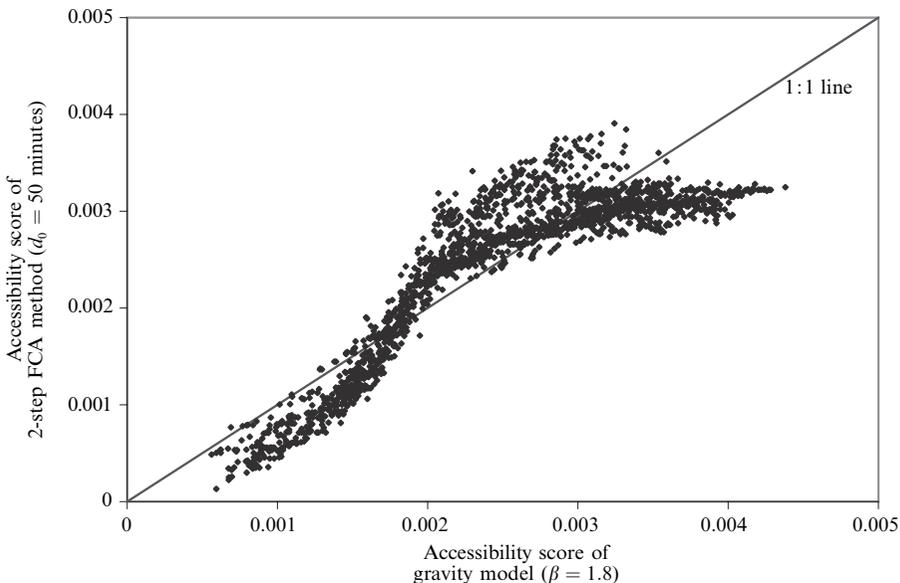


Figure 4. Accessibility measures by the two-step floating catchment area (FCA) and the gravity-based methods.

Our ongoing research will develop a comprehensive index of 'medical needs' based on factors including these demographic and socioeconomic variables (also see Field, 2000), and integrate it into the spatial accessibility measures discussed here.

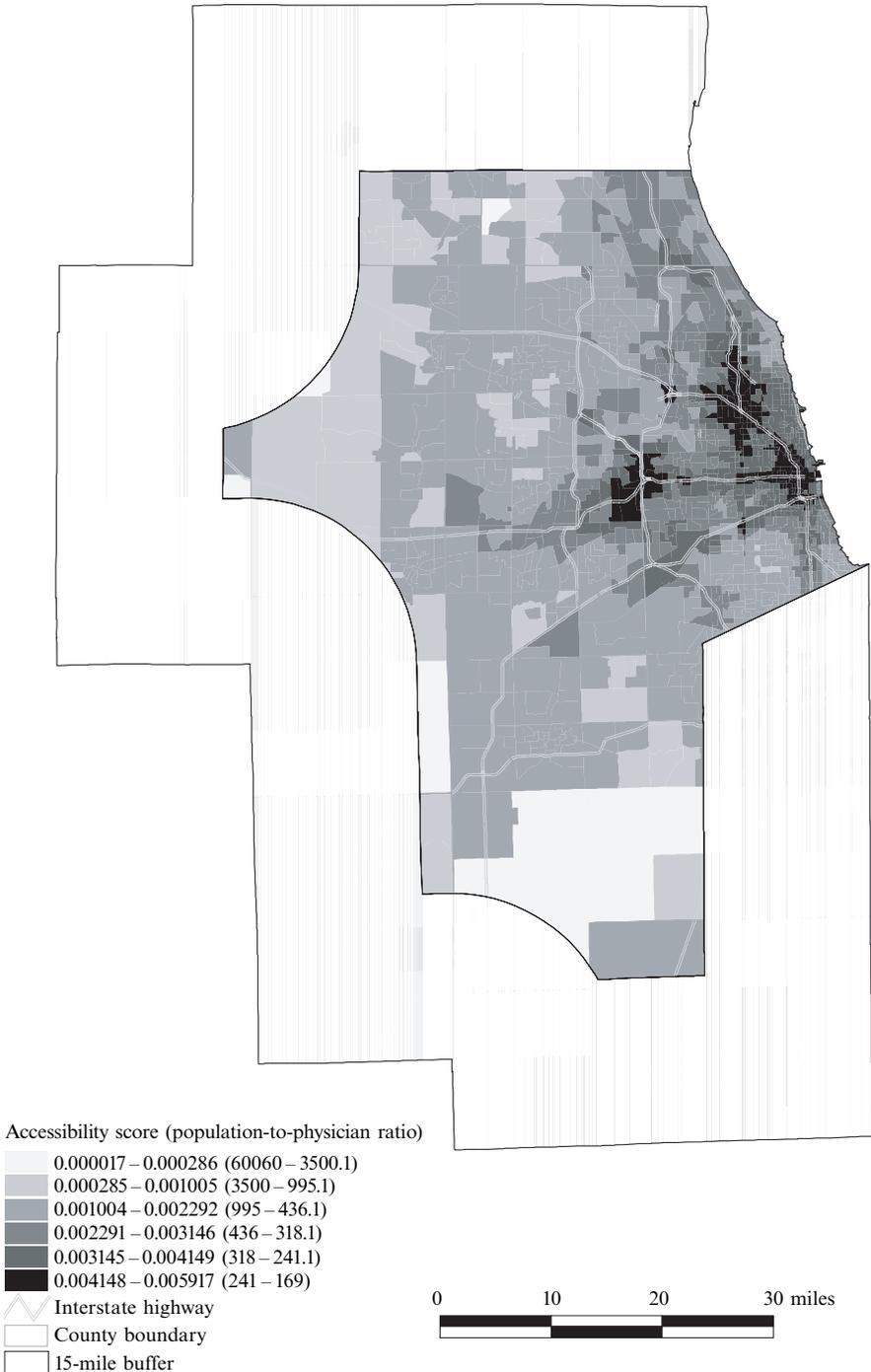


Figure 5. Accessibility to primary care in Chicago region by the two-step floating catchment area (FCA) method ($d_0 = 30$ minutes).

To highlight the spatial smoothing effect of gravity-based accessibility measures, figure 6 shows the result using $\beta = 1.0$. It shows a concentric pattern (better accessibility in areas closer to the city center) and much less spatial variability.

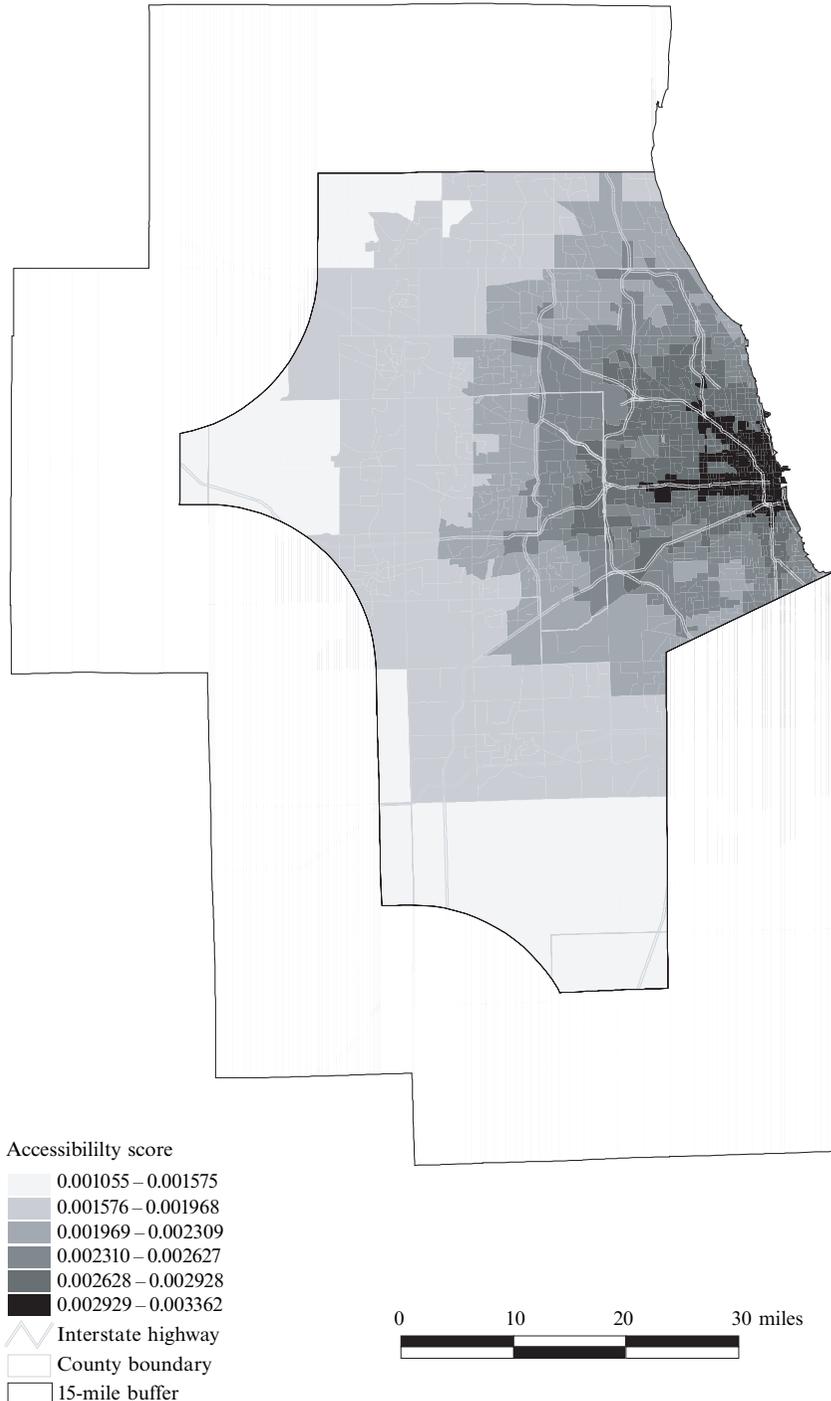


Figure 6. Accessibility to primary care in Chicago region by the gravity-based method ($\beta = 1.0$).

The gravity-based method defines 'accessible' as a continuous measure whereas the FCA method uses a dichotomous measure. Perhaps, for individuals, accessibility or inaccessibility to a physician location is a dichotomous decision. For an aggregated group of diverse individuals, the collective outcome reflects decisions based on different threshold travel times, and perhaps displays a continuous measure. However, one concern for the gravity-based method is that it allows for the tradeoff between the number of physicians and travel time. By the notion of the gravity model (assuming $\beta = 1.0$ for simplicity), a patient is as accessible to two physicians 20 minutes away as to one physician 10 minutes away. This may be considered questionable, particularly to people outside the field of geography. Perhaps more importantly, as shown earlier, the gravity-based method tends to give high accessibility scores in poor-access areas, where the designation of physician shortage areas is intended to locate. The gravity-based method also involves more computation and programming and is less intuitive. In summary, we are leaning towards recommending the two-step FCA method for helping measure primary care accessibility and define physician shortage areas. The principles of the two-step FCA method can be easily incorporated into existing shortage-designation practice because the necessary data and technology are now available. In a systematic and consistent way, the method implements some of the DHHS guidelines that are stated only conceptually. In a GIS environment, the method can be highly automated as long as necessary data are in place.

Summary and future work

In summary, by using population and physician data at finer geographic resolutions, this research uses the two-step floating catchment area (FCA) method and the gravity-based method to examine spatial accessibility to primary care in the Chicago region. Both methods are implemented in a GIS environment. The methods consider the interaction between physicians and patients across administrative borders and use travel times to measure the spatial barrier between them. Results from the methods reveal details of varying spatial accessibility to health care with finer resolution data. Based on this preliminary case study, we recommend the two-step FCA method, simpler and easier to interpret, for use in improving the designation of health professional shortage areas.

Future work can improve the research in at least three aspects. First, this research does not differentiate population with and without personal vehicles. For those without automobiles and having to depend on public transit (particularly, low-income and minorities), their accessibility to physicians is diminished to a great degree. This issue will be addressed when the 2000 Census with vehicle-availability data becomes available, and a more comprehensive study of accessibility considering aspatial factors will be conducted. Second, we will evaluate how the variation of accessibility corresponds to the distribution of population with various socioeconomic statuses and ethnicities, and assess whether minorities and low-income residents are disproportionately located in poor-access areas. Finally, we will compare the health care accessibility between 1990 and 2000, and examine how the accessibility has changed over time and whether the accessibility has been improved for some areas.

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APPENDIX
Table A1. Primary care physician and population by county in the study area, 2000.

County	Number of primary care physicians	Population	Population-to-physician ratio
Cook	15 795	5376 741	340.4 : 1
DeKalb	94	88 969	946.5 : 1
DuPage	2 991	904 161	302.3 : 1
Grundy	35	37 535	1072.4 : 1
Kane	557	404 119	725.5 : 1
Kankakee	150	103 833	692.2 : 1
Kendall	27	54 544	2020.1 : 1
Lake	1 550	644 356	415.7 : 1
McHenry	257	260 077	1012.0 : 1
Will	455	502 266	1103.9 : 1

Table A2. Guidelines for travel speed settings.

Category (CFCC) ^a	Population density (per km ²)	Area ^b	Speed limit (mph)
Interstate highways (A11–A18)	≥ 100	urban and suburban	55
	< 100	rural	65
US and state highways (A21–A38)	≥ 1 000	urban	35
	1 000 > density ≥ 100	suburban	45
	< 100	rural	55
Local roads (A41–A48)	≥ 1 000	urban	20
	1 000 > density ≥ 100	suburban	25
	< 100	rural	35

^aThe CFCC (census feature class codes) are used by the US Census Bureau in its TIGER/Line files.

^bSee figure A1 (over) for distribution.

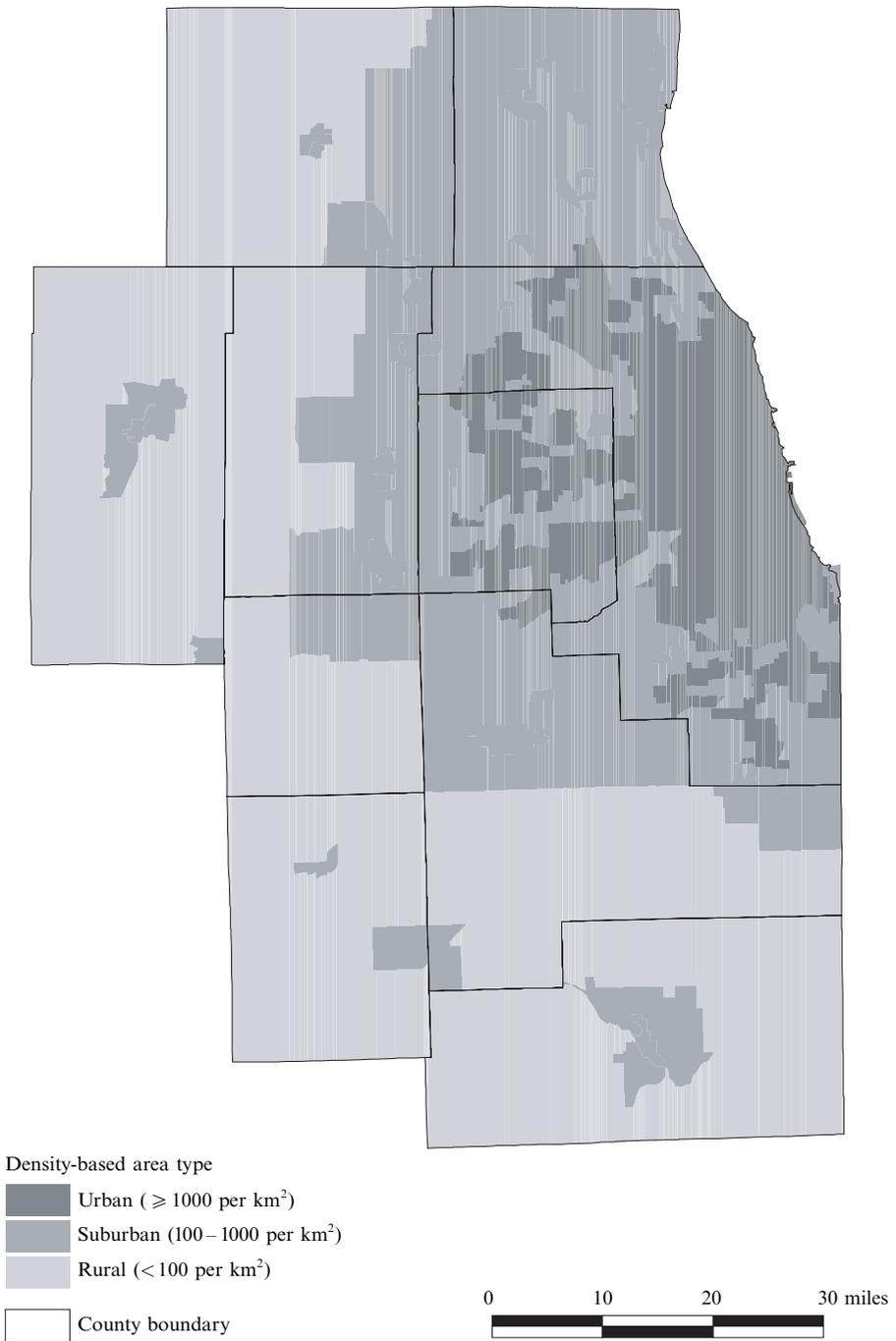


Figure A1. Population-density-based area types for travel-speed assignments.

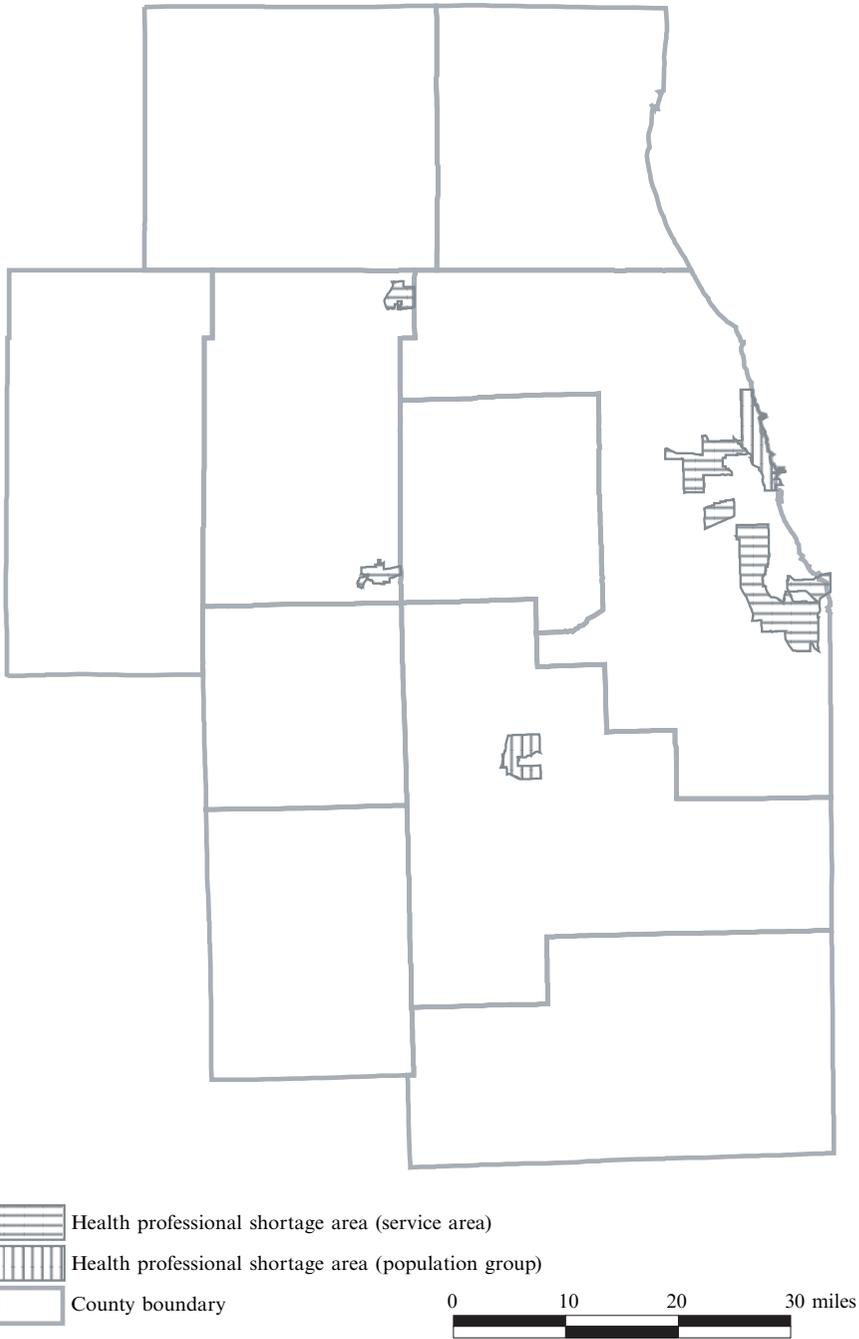


Figure A2. Designation areas of physician shortage (31 May 2001).