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## An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians

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### ABSTRACT

This paper presents an enhancement of the two-step floating catchment area (2SFCA) method for measuring spatial accessibility, addressing the problem of uniform access within the catchment by applying weights to different travel time zones to account for distance decay. The enhancement is proved to be another special case of the gravity model. When applying this enhanced 2SFCA (E2SFCA) to measure the spatial access to primary care physicians in a study area in northern Illinois, we find that it reveals spatial accessibility pattern that is more consistent with intuition and delineates more spatially explicit health professional shortage areas. It is easy to implement in GIS and straightforward to interpret.

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### 1. Introduction

Access to primary healthcare is recognized as an important facilitator of overall population health (Guagliardo, 2004) because primary care is the first line of defense for the population and a critical part of preventive care. Good primary care can prevent or reduce unnecessary expensive specialty care (Lee, 1995; Luo, 2004). To ensure adequate access to primary care, health service planners and policy makers need accurate and reliable measures of accessibility so that true physician shortage areas can be accurately identified and resources allocated to those needy areas to alleviate the problem.

Access to health care in a given location is influenced by many factors, including the availability of health services in the area (supply), the number of people living in that location (demand), the population's health status, the socio-economic and financial resources available to the population, people's knowledge about health and the health care system, and geographical impedance between population and health services (Aday and Andersen, 1974). Health care accessibility has been classified into two broad categories: revealed accessibility and potential accessibility (Joseph and Phillips, 1984; Phillips, 1990; Thouez et al., 1988), with the former focusing on actual use of health care services and the latter emphasizing the aggregate supply of medical care resources available in an area. Based on spatial factors (e.g.,

geographic location, distance), non-spatial factors (e.g., social class, income, age, sex, etc; Joseph and Phillips, 1984) and their interactions (Meade et al., 1988) each of the broad categories can be further divided into spatial accessibility and non-spatial accessibility (i.e., the  $2 \times 2$  matrix of Khan, 1992). This paper will focus only on the methodology of measuring potential spatial accessibility, because identifying where the truly underserved populations are located is the essential first step toward any meaningful and effective government intervention programs (Luo, 2004; Guagliardo, 2004). The integration of both spatial and non-spatial factors has been discussed elsewhere (Wang and Luo, 2005) and the enhancement discussed here can be easily incorporated into that framework.

#### 1.1. Background on physician shortage designation in the US

Among the many factors that influence access to health care services, two of them are critical: physician supply and population demand. Both of these are spatially distributed, but it is rare that their distributions perfectly match (Luo, 2004). Health care access problems are especially pronounced, for example, 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 health care access problems, including providing incentives or awarding financial assistance to providers serving designated shortage areas through the National Health Service Corps Program, the Medicare Incentive Program, and the J-1 visa waiver program, among others (GAO, 1995).

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These US federal programs, administrated by the Department of Health and Human Services (DHHS; GAO, 1995; Lee, 1991), depend on two main systems for identifying shortage areas. One designates health professional shortage areas (HPSAs), the other medically underserved areas or populations (MUAs/MUPs). A summary of the historical development of the two systems can be found in Ricketts et al. (2007). Briefly, the criteria for designating HPSA are the following: (1) the geographic area involved is rational for the delivery of health services, i.e., a rational service area; (2) the ratio of population to full-time-equivalent (FTE) physicians exceeds a specified shortage criterion within the area; and (3) resources in contiguous areas are overutilized, excessively distant, or otherwise inaccessible. For primary care HPSA, the specified threshold population-to-physician ratio is 3500:1 (or 3000:1 if there are unusually high needs). In addition, the HPSA can also be designated for a population group (e.g., low-income population) or facility (e.g., a correctional center). MUAs or MUPs are designated on the basis of four factors of health service need: (1) population to FTE primary care physician ratio; (2) infant mortality rate; (3) percentage of the population with incomes below the poverty level; and (4) percentage of the population aged 65 and older. These four variables are applied to a rational service area to obtain a single Index of Medical Underservice (IMU) score ranging from 0 to 100, with 0 representing the most underserved and 100 the best-served areas. A rational service area with a score of 62 or less qualifies for designation as a MUA/MUP.

The rational service area concept used in both HPSA and MUA/MUP is defined for non-metropolitan areas as (a) a whole county or (b) groups of contiguous counties, minor civil divisions, or census county divisions with population centers within 30 min travel time of each other; for metropolitan areas, the rational service area is defined as a group of census tracts that represent a neighborhood of homogeneous socio-economic and demographic characteristics. The existing practice of designating either an HPSA or MUA/MUP is a tedious process that involves complicated rules for defining the rational service area, estimating FTE, evaluating contiguous resources, and so on. Detailed information on the designation process is presented in DHHS (1980), Lee (1991), GAO (1995) and the website of Health Resources and Services Administration (HRSA), US Department of Health and Human Services (<http://bhpr.hrsa.gov/shortage/index.htm>, last accessed March 20, 2009).

Although DHHS shortage area designation methods also take into account some non-spatial factors such as age and socio-economic status, they are primarily regional availability measures that quantify the distribution of supply versus demand within a predefined region, often expressed as a ratio of population to practitioner (or its variation; Joseph and Phillips, 1984). The advantage of such a regional availability approach is that it is simple and thus straightforward to implement as the data for physicians and population are readily available and such boundaries can be easily located in the real world (Florin et al., 1994). In addition, it is also convenient to administer federal funding programs because the government infrastructure is already in place (Florin et al., 1994).

However, two implicit assumptions found in the regional availability approach draw sharp criticisms (e.g., Kleinman and Makuc, 1983; Wing and Reynolds, 1988): (1) that people within the region have equal access to the physicians within the same region (i.e., the subregion variation of supply and demand and “distance decay” of utilization behavior are ignored) and (2) that people within the region do not go beyond that region to seek care (i.e., the boundary of the region is impermeable or self-contained). These assumptions are not always true in the real world (Kleinman and Makuc, 1983; GMENAC, 1980; Wing and Reynolds, 1988; GAO, 1995; COGME, 1998). They also have different requirements

of the scale of the data. The first assumption is realistic only with spatially disaggregated data (e.g., census tract or even smaller areal units) as described by Bullen et al. (1996), Curtis and Taket (1989), and Kivell et al. (1990), whereas the second assumption requires spatially aggregating data to higher levels (e.g., groups of counties; Makuc et al., 1991).

Although step (3) of the HPSA method is intended to consider adjacent areas, the physician-to-population ratios are still calculated within their respective boundaries and the actual interaction across boundaries is not accounted for. Even the recent proposed revisions of the shortage area designation (DHHS, 1998; Ricketts et al., 2007) are still primarily regional availability measures. The fact that the whole county or group of contiguous counties can still be defined as rational service areas in the current DHHS systems suggests that the existing methods can easily lead to overestimation in some areas and underestimation in others, and thus funding for programs aimed at alleviating access problems based on such designation may not be channeled to where it is most needed (GAO, 1995).

## 1.2. Measures of potential spatial accessibility

The problems of regional availability measures have been long recognized in geography (e.g., Openshaw and Taylor, 1981), but are still not well resolved. This is partially due to the complexity of the issue, i.e., both the supplies and demands are spatially distributed and are likely overlapping, and competition exists among suppliers and consumers (e.g., Huff, 1963, 1964). The alternative to regional availability measures is the regional accessibility approach, which uses a gravity model formulation to factor interaction between supply and demand located in different regions with distance decay, thereby addressing the problems of the regional availability approach (Weibull, 1976; Joseph and Bantock, 1982; Joseph and Phillips, 1984; Shen, 1998; Huff, 2000; Wang and Minor, 2002; Guagliardo, 2004; Yang et al., 2006). The gravity model as applied to measure access to physician usually takes the following form:

$$A_i^G = \frac{\sum_{j=1}^n S_j d_{ij}^{-\beta}}{\sum_{k=1}^m P_k d_{kj}^{-\beta}} \quad (1)$$

$A_i^G$  is the gravity-based index of accessibility at population location  $i$ , where  $n$  and  $m$  are the total numbers of physician locations and population locations, respectively. The denominator term represents a measure of the availability of physicians at location  $j$  to all population ( $P_k, k = 1, 2, \dots, m$ ).  $S_j$  is the number of physicians at location  $j$ ;  $d_{kj}$  and  $d_{ij}$  are the distance or travel time, and  $\beta$  is the friction-of-distance coefficient.

While conceptually more complete, a gravity model like this is not intuitive to interpret and requires more data input to calculate: the location of supply and demand (Joseph and Phillips, 1984), traffic network, and travel time analysis between supply and demand. In addition, the frictional coefficient  $\beta$  in distance decay function has to be determined by physician–patient interaction data and may be region specific (Huff, 2000).

The two-step floating catchment area method (2SFCA), first proposed by Radke and Mu (2000) but later modified by Luo and Wang (2003a, b), is a special case of gravity model. It not only has most of the advantages of a gravity model, but is also intuitive to interpret, as it uses essentially a special form of physician-to-population ratio. The method is implemented in the following two steps (Luo and Wang, 2003b; Wang and Luo, 2005):

Step1: For each physician location  $j$ , search all population locations ( $k$ ) that are within a threshold travel time ( $d_0$ ) from location  $j$  (this is the catchment of physician location  $j$  or

catchment  $j$ ), and compute the physician-to-population ratio,  $R_j$ , within the catchment area:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k} \quad (2)$$

where  $P_k$  is the population at location  $k$  whose centroid falls within catchment  $j$  ( $d_{kj} \leq d_0$ ),  $S_j$  the number of physicians at location  $j$ , and  $d_{kj}$  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 (derived in step 1),  $R_j$ , at these locations:

$$A_i^F = \sum_{j \in \{d_{ij} \leq d_0\}} R_j = \sum_{j \in \{d_{ij} \leq d_0\}} \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k} \quad (3)$$

where  $A_i^F$  represents the accessibility of population at location  $i$  to physicians based on the two-step floating catchment area method,  $R_j$  is the physician-to-population ratio at physician location  $j$  whose centroid falls within the catchment centered at population location  $i$  (i.e.,  $d_{ij} \leq d_0$ ), and  $d_{ij}$  the travel time between  $i$  and  $j$ . A larger value of  $A_i^F$  indicates a better access to physicians at that population location. The first step assigns an initial ratio to each catchment (or service area) centered at physician locations, and the second step sums up the initial ratios in the overlapping service areas where residents have access to multiple physician locations. Note that Eq. (3) is basically a ratio of physician (supply) to population (demand), with only selected physicians and population entering the numerator and denominator.

The 2SFCA method has been used in a number of recent studies measuring health care accessibility (e.g., Guagliardo, 2004; Albert and Butar, 2005; Yang et al., 2006; Langford and Higgs, 2006; Wang, 2007; Cervigni et al., 2008; Wang et al., 2008). However, it has two limitations (Luo and Wang, 2003b): (1) it does not differentiate distance impedance within the catchment (i.e., all population locations within the catchment are assumed to have equal access to physicians) and (2) it is a dichotomous measure (i.e., all locations outside of the catchment have no access at all). Several studies since then have attempted to address the shortcomings. Guagliardo (2004) proposed using a kernel density (KD) function to approximate the distance decay for both physician and population and obtaining provider-to-population ratio based on physician density raster and population density raster. Yet, his study used a uniform base radius (3 miles) for the KD function, which is equivalent to the straight-line distance for the catchment. Yang et al. (2006) compared the KD method with 2SFCA and found that 2SFCA performs better than KD, but pointed out the need to vary the radius of service area according to the type of provider or the type of neighborhood.

In their study of measuring access to cancer care facilities in the US, Alford et al. (2008) introduced Gaussian weights to the demand side (second step) of 2SFCA to account for the distance decay and they used the gridded raster population data LandScan developed by the Oak Ridge National Laboratory (ORNL). Nonetheless, they did not apply Gaussian weights to the supply side (first step), nor did they offer any theoretical linkage to gravity model.

The University of New Mexico Division of Government Research developed an unpublished model that divides the space around each physician zip code centroid into three circular zones (<http://www.unm.edu/~dgrint/dgr.html>, last accessed March 20, 2009). The closest zone (<35 miles) is friction-free. The farthest zone (>100 miles) is considered inaccessible, and for the zone in between, physician service is discounted by the inverse of square of distance. This method uses zip code for both population and

physician, which may result in loss of resolution and the introduction of errors. It uses straight-line distance, rather than street network distance or travel time, which are better measures of impedance (Wang and Minor, 2002).

Next we will synthesize these previous ideas in the enhanced two-step floating catchment area method to address the shortcomings, while maintaining theoretical association with the gravity model and its accompanying advantages.

## 2. Methodology

Building on previous research, this paper presents an enhancement to the 2SFCA method by applying weights to differentiate travel time zones, in both the first step and the second step, thereby accounting for distance decay. In the following discussion, we assume that the population data is in the gridded raster format such as LandScan. The same principle applies to vector-based population data. In order to differentiate accessibility within a catchment, multiple travel time zones within each catchment are obtained using the ArcGIS Network Analyst and assigned with different weights according to the Gaussian function (Kwan, 1998; Wang, 2007). The method is implemented in two steps:

Step 1: The catchment of physician location  $j$  is defined as the area within 30-min driving zone (Lee, 1991). Within each catchment, compute three travel time zones with minute breaks of 0–10, 10–20 and 20–30 min (zones 1–3, respectively). Search all population locations ( $k$ ) that are within a threshold travel time zone ( $D_r$ ) from location  $j$  (this is catchment area  $j$ ), and compute the weighted physician-to-population ratio,  $R_j$ , within the catchment area as follows:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \in D_r\}} P_k W_r} = \frac{S_j}{\sum_{k \in \{d_{kj} \in D_1\}} P_k W_1 + \sum_{k \in \{d_{kj} \in D_2\}} P_k W_2 + \sum_{k \in \{d_{kj} \in D_3\}} P_k W_3} \quad (4)$$

where  $P_k$  is the population of grid cell  $k$  falling within the catchment  $j$  ( $d_{kj} \in D_r$ ),  $S_j$  the number of physicians at location  $j$ ,  $d_{kj}$  the travel time between  $k$  and  $j$ , and  $D_r$  the  $r$ th travel time zone ( $r = 1-3$ ) within the catchment.  $W_r$  is the distance weight for the  $r$ th travel time zone calculated from the Gaussian function, capturing the distance decay of access to the physician  $j$ .

Step 2: For each population location  $i$ , search all physician locations ( $j$ ) that are within the 30 min travel time zone from location  $i$  (that is, catchment area  $i$ ), and sum up the physician-to-population ratios (calculated in step 1),  $R_j$ , at these locations as follows:

$$A_i^F = \sum_{j \in \{d_{ij} \in D_r\}} R_j W_r = \sum_{j \in \{d_{ij} \in D_1\}} R_j W_1 + \sum_{j \in \{d_{ij} \in D_2\}} R_j W_2 + \sum_{j \in \{d_{ij} \in D_3\}} R_j W_3 \quad (5)$$

where  $A_i^F$  represents the accessibility of population at location  $i$  to physicians,  $R_j$  the physician-to-population ratio at physician location  $j$  that falls within the catchment centered at population  $i$  (that is,  $d_{ij} \in D_r$ ), and  $d_{ij}$  the travel time between  $i$  and  $j$ . The same distance weights derived from the Gaussian function used in step 1 are applied to different travel time zones to account for distance decay.

Just as 2SFCA has proven to be a special case of the gravity model, where the friction-of-distance exponent equals 1 in the catchment and 0 outside (Luo and Wang, 2003b), E2SFCA is also a special case of gravity model. The Gaussian weight used in E2SFCA is a way to implement the distance decay term ( $d_{kj}^{-\beta}$  and  $d_{ij}^{-\beta}$ ) in gravity model. If we assume equal access within each of the three

travel time zones, zero access beyond the third zone, and replace the distance decay terms with corresponding weights, Eq. (1) becomes Eq. (5).

The advantage of E2SFCA is that multiple distance decay weights substitute the dichotomous 0 and 1 in 2SFCA; so it solves the problem of not differentiating accessibility within the catchment and thus is theoretically more analogous to the gravity model. The discretized consideration of distance decay (by travel time zones) in E2SFCA is a reasonable approximation to the continuous gravity model because, in reality, people would not mind a few minutes of difference in travel time to seek care. This approximation makes the result of E2SFCA straightforward to interpret and easy to use, because it is essentially a weighted physician-to-population ratio. With the advances in GIS technology and availability of street network data, E2SFCA can be easily implemented with GIS software.

### 3. Study area and data

To illustrate the advantages of the E2SFCA method, we apply it to examine the spatial accessibility to primary care physicians in a group of nine counties surrounding DeKalb in northern Illinois (Luo and Wang, 2003a; Luo, 2004) and compare the results with those derived from 2SFCA and the HPSA of 2000 (DHHS, 2000). The nine counties are: Winnebago, McHenry, Boone, Ogle, Kane, DeKalb, Lee, Kendall, and La Salle and are mostly suburban or rural, located west of Chicago. (See Fig. 1 for location.) The 2000 census data show that there are 1,239,363 people living in the study area.

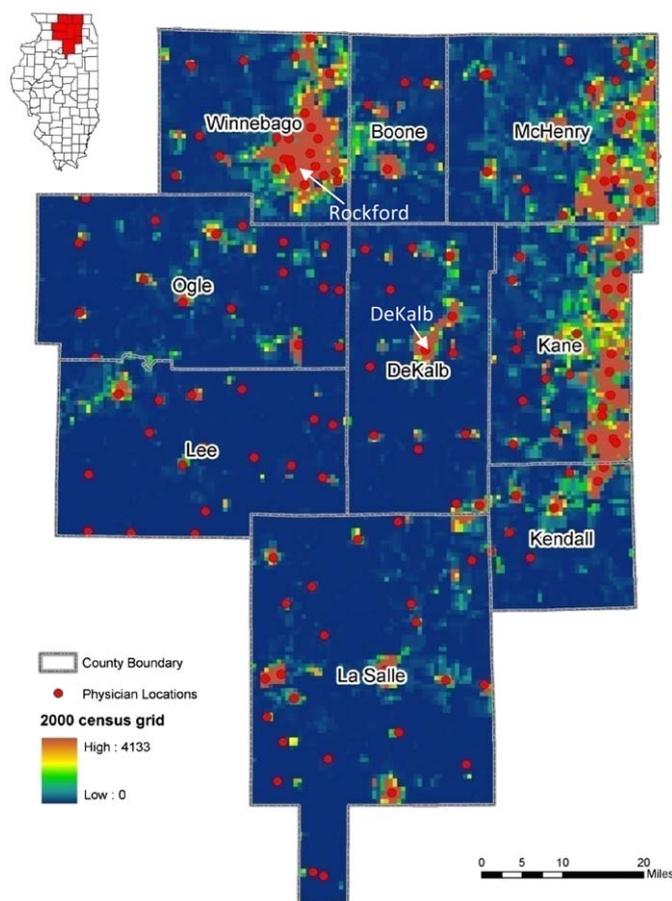


Fig. 1. Physician locations and 2000 census grid in study area.

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 research uses the same dataset as that in Luo and Wang (2003a) and approximates physician location with the zip code centroid of the physician's work address. The zip code data are used because a significant number of records in the Physician Master File have only PO Box addresses, which are not feasible for geocoding. There are 1748 primary care physicians located in the 163 facilities in the study area. The analysis of multiple-site practices is important for the accurate assessment of medical service availability (Cromley and Albertsen, 1993), but since the main focus of the paper is on methodology of measuring potential spatial access we did not consider multiple-site practices. The same dataset is used with both 2SFCA and E2SFCA for comparison. Fig. 1 shows the location of the study areas, the physician locations by zip code centroids, and the gridded population data.

Unlike previous work, this research uses US 2000 Census Grid data created in SEDAC project at Columbia University because LandScan data are available only for the current year. The data were derived from the original 2000 census data by taking population and housing counts to the block level and proportionally allocating the count in the census blocks to a latitude–longitude quadrilateral grid. The resolution is 30 arc-second (~1 km). The regular grid cell in raster data is better for overlapping travel time zone analysis than vector data, and the graphic output is usually more aesthetically pleasing. Detailed information of the US 2000 Census Grid can be found at <http://sedac.ciesin.columbia.edu/> (last accessed, March 20, 2009). Unlike most prior work using straight-line distances or travel time estimation, this research uses detailed and updated street network data that come from 2008 ESRI data CD and ESRI ArcGIS Network Analyst 9.3 to accurately estimate travel time zones around physician locations.

### 4. Results

The result of applying 2SFCA to the study area is shown in Fig. 2. Two sets of weights are used in the E2SFCA method. Weight set 1 (= 1.00, 0.68, and 0.22 for the three travel time zones) represents a slower distance decay (Fig. 3), whereas weight set 2 (= 1.00, 0.42, and 0.09) represents a sharper distance decay (Fig. 4). A comparison of Figs. 2 and 3 shows that, overall, the two methods generate similar physician accessibility patterns. The majority of the low accessibility areas are rural areas outside the major population centers (e.g., Rockford and DeKalb). The result of E2SFCA reveals more details of accessibility than 2SFCA, because 2SFCA does not differentiate the spatial variation within each catchment. For example, in the area around Rockford, E2SFCA shows a concentric pattern of accessibility with higher values near the population center and lower values at its periphery (Fig. 3), whereas 2SFCA displays relatively uniform high accessibility from the center to periphery (Fig. 2). Clearer hierarchy structures can be observed in the other urban and suburban areas in E2SFCA (compare Figs. 2 and 3).

One criticism on 2SFCA is that the accessibility is overrated in the overlapping areas of physician catchments, as the residents in those areas are assumed to have services from all physicians whose service areas are overlapping there. This might not always be true because people at the outer rim of a catchment may not be fully served by the physicians near the center of the catchment. This problem is solved in E2SFCA, since distance decay within the

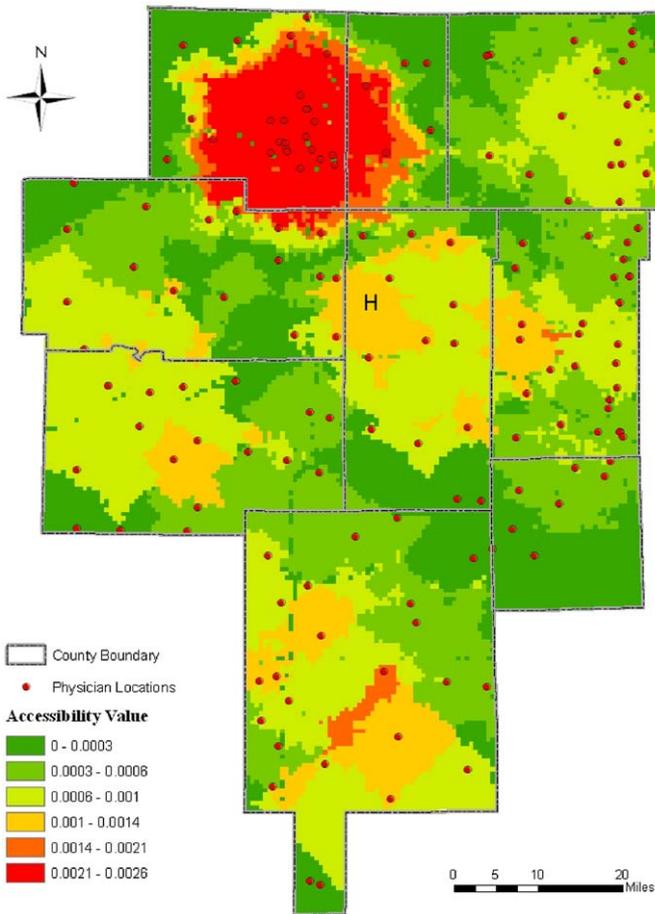


Fig. 2. Result of 2SFCA method.

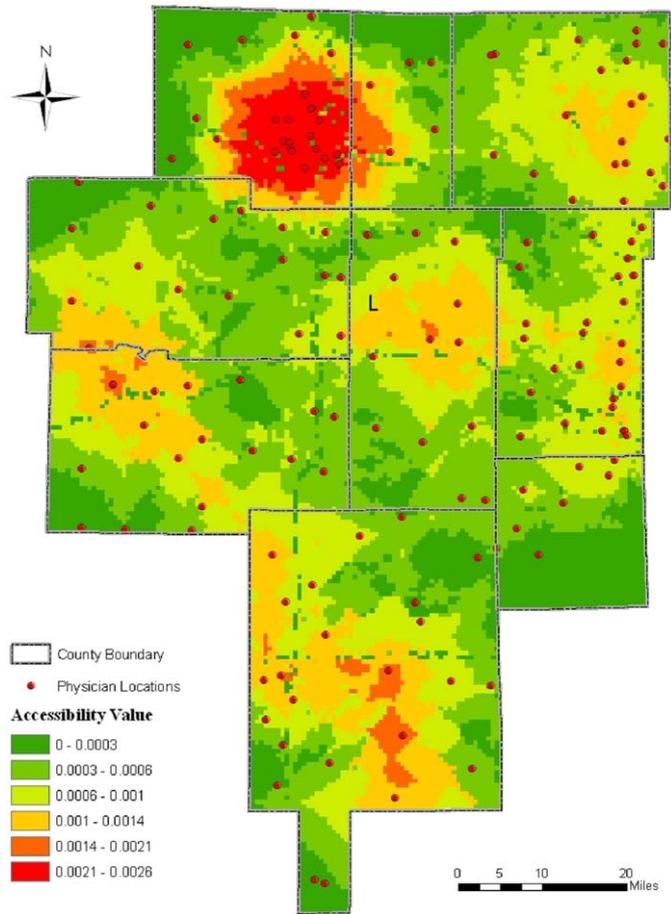


Fig. 3. Result of E2SFCA method applying weight 1.

catchment is taken into consideration through the distance decay weights. For example, according to the 2SFCA method, the rural area northwest of DeKalb actually has accessibility equal to or higher than that of the area closer to the City of DeKalb (see the area labeled H in Fig. 2), a result that is counterintuitive. With the E2SFCA method, the accessibility of the same area becomes equal to or lower than that of areas closer to DeKalb (see the area labeled with L in Fig. 3). With a sharper distance decay structure (weight 2), the accessibility pattern is more of a concentric pattern around DeKalb, the highest near population center and the lowest farther away (compare Figs. 1, 3, and 4). This observation holds true for the rest of the study area, with low accessibility in suburban and rural regions and high accessibility around urban centers (hot spots; See Fig. 4).

Fig. 5 shows the plot of accessibility at each population grid cell, as generated by the 2SFCA and E2SFCA methods. The 2SFCA method tends to overestimate accessibility compared with the E2SFCA method (more data points above the 1:1 line), especially in areas with low accessibility. This is because of the equal access within catchment assumption in 2SFCA. In fact, using the commonly used 1:3500 physician-to-population ratio as standard, the 2SFCA method identifies 42,916 persons without adequate access to primary care physician in the study area, whereas 60,079 persons are identified without adequate access by the E2SFCA method with the preferred weight set 2 distance decay structure (see Table 1).

What is more informative is the comparison of spatial distribution of shortage areas identified with different methods:

2SFCA, E2SFCA (with two different weights), and the 2000 HPSA as published by DHHS (DHHS, 2000). HPSAs in the study area are mostly partial counties (DHHS, 2000) represented as townships (in Ogle and Lee counties) and census tracts (west Rockford area in Winnebago County). The west Rockford HPSAs are apparently related to non-spatial factors (low-income population groups), not explicitly considered in this paper. The HPSAs in Ogle and Lee counties generally covered the shortage areas identified by 2SFCA and E2SFCA, but overestimated their spatial extents. In addition, the HPSAs also missed many other shortage areas identified by 2SFCA and E2SFCA methods. These shortage areas are usually located between the population centers and along the edge of the study area. Since the study area is limited to the DeKalb and surrounding counties, the actual health care status for the areas on the edge of the study area may need further examination as physician data from the neighboring states/counties are not included (i.e., these areas are subject to the classical edge effect arising in spatial analysis).

As shown in Fig. 5, the 2SFCA method tends to overestimate accessibility because distance decay is not considered, and thus identifies smaller total shortage areas (compare Figs. 6(a) and (b), see also Table 1). The sharper distance decay weight (weight 2) used in E2SFCA identifies greater total shortage area (in terms of both physical area and population) than a slower distance decay weight (weight 1). The policy implication is that using the E2SFCA method would more explicitly identify and delineate HPSAs. This would help allocate the limited resources to the most needy places.

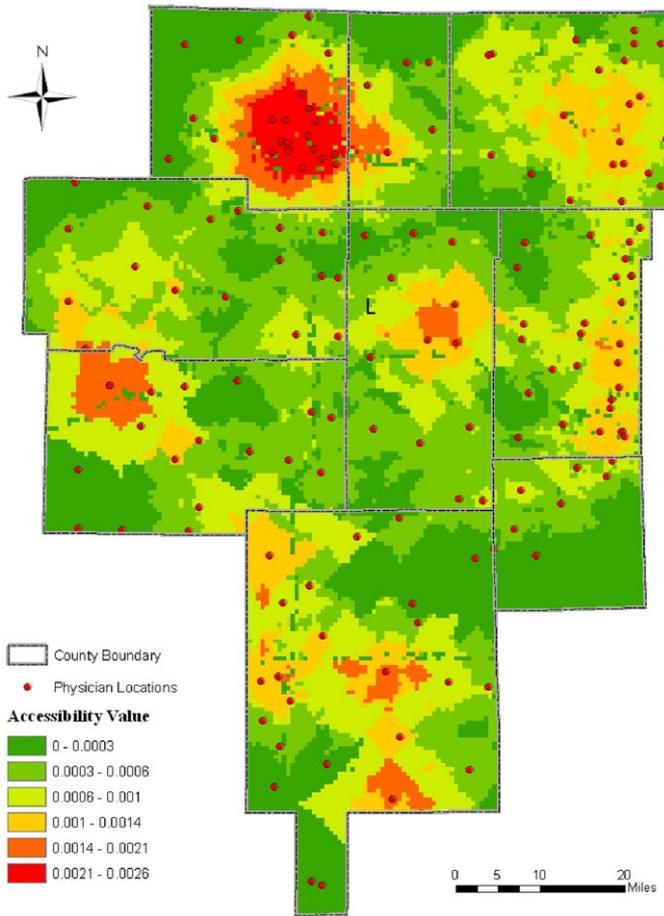


Fig. 4. Result of E2SFCA method applying weight 2.

### 5. Discussion

The E2SFCA method as shown in the above case study addresses the shortcomings of 2SFCA but maintains its advantages. Several issues remain for further study. First, what is the appropriate functional form for the distance decay weights? In this study we used the Gaussian function weight to account for the distance decay and we compared two sets of weights. Other functional forms can also be used depending on the type of accessibility. For example, for access to cancer care facility, a slower decay function could be used; for access to pharmacy, a sharper decay function could be used. Second, what is the scale of temporal resolution for estimating travel time? In this study, we used 10-min interval travel time for the subzones within the catchment. This can be varied according to the type of accessibility and the resolution needed. Third, what is the appropriate catchment size? As pointed by Yang et al. (2006), the catchment size may also be varied according to the type of provider or the type of neighborhood. For example, in rural areas, the catchment size may be bigger; in urban areas smaller. The optimal size can be determined by incrementally increasing the size of catchment until the base population within the catchment meets a threshold value (Tiwari and Rushton, 2005). In addition, the size of the catchment does not have to be the same for step 1 and step 2. Physicians in an urban center may serve a large area including surrounding small towns, requiring large catchment for step 1, but population in an urban center is less likely to seek care in a nearby small town, resulting in small catchment for step 2. To properly address these issues, detailed surveys of actual utilization of health services would be necessary.

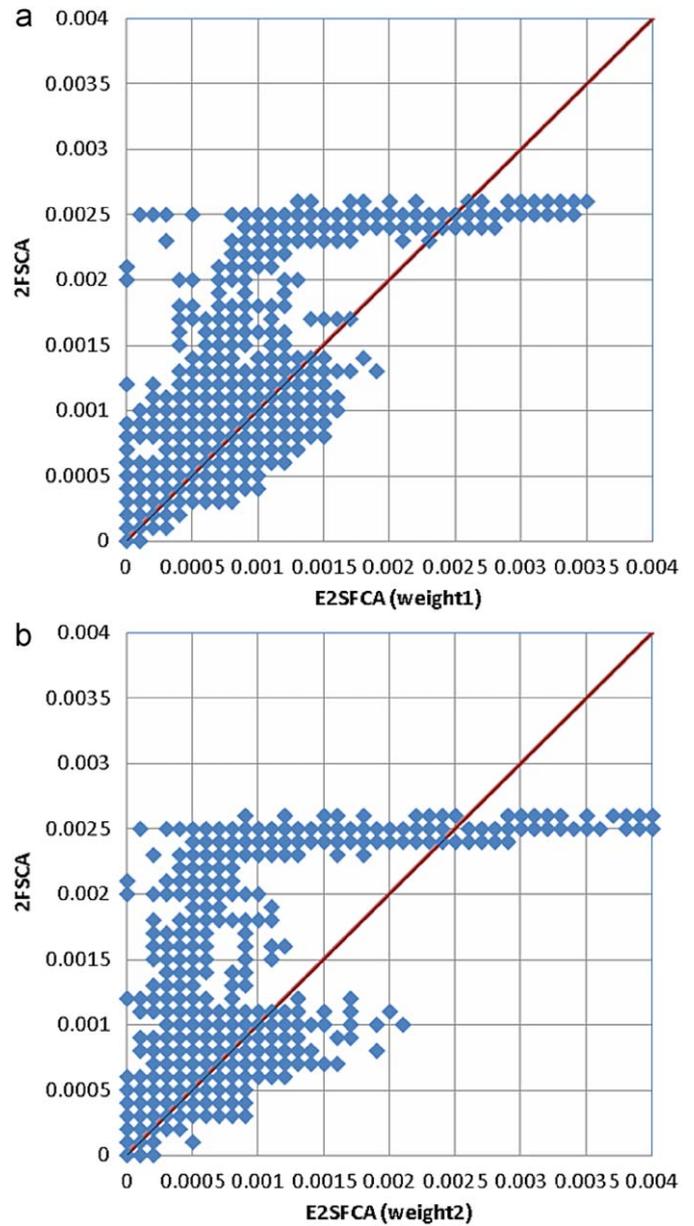


Fig. 5. Comparison of accessibility by 2FSCA and E2SFCA: (a) weight 1 and (b) weight 2.

Table 1  
Physician shortage area statistics.

Method	Area of shortage area (km <sup>2</sup> )	Population under physician shortage
HPSA (2000)	21,162.9	44,811
2SFCA	23,418.5	42,916
E2SFCA (weight1)	27,951.3	42,685
E2SFCA (weight2)	42,209.8	60,079

### 6. Conclusion

Built on previous research, this paper presents an enhancement of the existing 2SFCA method for measuring spatial accessibility by introducing weights to different travel time zones within a catchment to account for the distance decay. The discretized consideration of distance decay (by travel time zones)

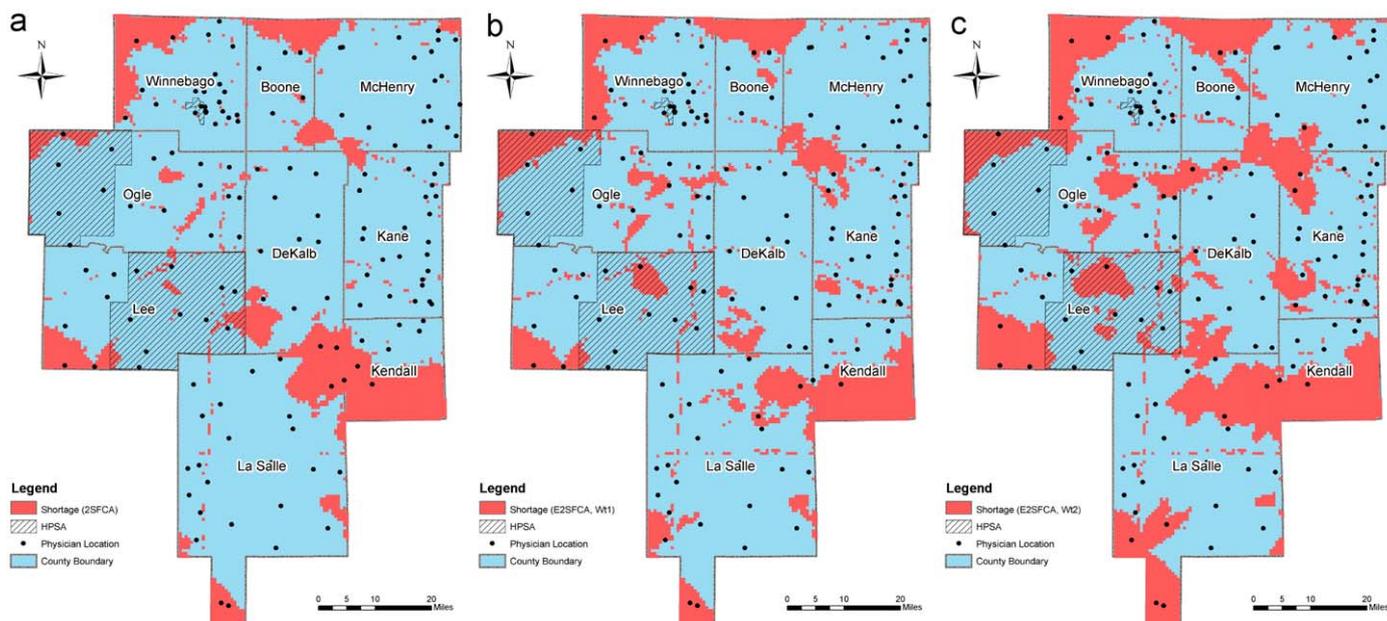


Fig. 6. Spatial distribution of shortage areas identified with 2SFCA (a), E2SFCA with weight1 (b), and weight 2 (c), along with published HPSA of 2000 by DHHS.

in E2SFCA is justified because, in reality, people would not mind a few minutes of difference in travel time to seek care. The travel time zones can be easily derived with ArcGIS Network Analyst tool. The advantage of E2SFCA is that it considers distance decay in both steps, which has solid theoretical foundation in gravity model as it is another special case of gravity model. Furthermore, E2SFCA is much easier to implement in GIS and more straightforward to interpret because it is an elaborated form of the familiar ratio between supply and demand (i.e., weighted ratio). The weight can take different forms and can be adjusted for different applications. For example, for measuring accessibility to cancer care facility, the weight might change slowly with distance; for measuring accessibility to pharmacy services, the weight may decay more sharply with distance. In addition, the catchment size can also be varied to account for the difference in base population in rural vs. urban areas and in step 1 vs. step 2. More survey-based studies are needed to determine the proper decay function and catchment size. The case study of applying this new method in northern Illinois showed that E2SFCA reveals a spatial accessibility pattern that is more consistent with intuition than the 2SFCA method and identifies more persons with inadequate access to primary care physicians. Incorporating E2SFCA into existing practices of designating physician shortage area would allow the government agencies to more precisely allocate limited healthcare resources to the most needy populations. In addition, the E2SFCA has great potential to be used in other areas such as measuring job accessibility.

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