Analyzing Location-Based Accessibility to Dental Services: An Ohio Case Study

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Abstract

Oral health is important to overall health. Therefore, dental services should be available and accessible in order for patients to receive care. ***Objective:*** *This study aims to identify regional inequities in dental provider location and suggest an innovative methodology that could be useful in establishing new dental facilities that are geographically accessible.* ***Methods:*** *Using a census of dentist locations for the state of Ohio in 1998, geographical accessibility to dental care was analyzed. A geographic information systems (GIS)-based model to evaluate the regional distribution of dentists was developed. In this article, it is applied to estimate the number of new dental facilities needed based on the geographical proximity or distance to nearest dentist or dental facility. Results are interactively displayed and mapped with GIS for visualization.* ***Results:*** *Four hundred thirteen of 1,008 zip codes in Ohio did not have dentists. Using a service standard of* S = *5 (all zip codes without dentists must be within 5 miles of a zip code with a dentist), 307 zip codes were not served by dentists. With a standard of* S = *10, only 45 zip codes in Ohio were not served by dentists, with only 24 additional offices needed to be located to allow accessibility to a dentist within 10 miles.* ***Conclusions:*** *Using GIS and geographical techniques to reveal and solve the potential locational inequities in accessibility to dental care, this work links oral health policy with geographical techniques.*

Key Words: accessibility, dental services, GIS, spatial analysis techniques

Introduction

The availability of dental care services to populations is important. Regular dental visits allow individuals to avoid potential diseases and maintain good oral and general health. In addition to commonly known dental and oral problems associated with failing to receive care, recent studies suggest that lack of dental care may also correlate with systemic diseases such as cardiovascular disease and low birth weight (1,2). In the United States, 1996 dental care utilization rates were estimated to be approximately 44 percent, with a goal of reaching 56 percent by 2010 (3). To improve dental service utilization, the issue of access to dental care is critical (4). However, this represents a challenge as the growing literature on access to dental care suggests that multiple factors interact to limit an individual's ability to receive dental care (5-8). Current evidence indicates that the poor, minorities, the uninsured, and people in poor health are most at risk as they often lack the ability to pay for dental services (9).

Discussions on access to care in dentistry include the consideration of the geographical, or *spatial dimension*, of access to dental care. This has led us to pose questions as to whether there are dentists present in given areas, or at least in close proximity that patients could visit, if able. Computer-based tools known as geographic information systems (GIS) that facilitate the mapping and analyzing of geographical data may be applied to the field of dentistry (9). Some of this early GIS work in dentistry (9) is similar to what has been known in the broader GIS community; that the analytical and visual capabilities of GIS are invaluable tools for improving analysis and decision making (10).

Accessibility. In general, accessibility is the ability to reach goods, services, activities, and destinations in geographic space (11,12). Accessibility is frequently conceived in urban contexts, where sprawling land development, excessive vehicular travel, and congestion hinder people's ability to travel and visit needed locations (13). Accessibility is also relevant to health care service provision (11,14). People must be able to physically reach health care facilities in order to receive care. Dentistry is no different in this regard; facilities must be relatively close or proximal to patients for dental care or services to be rendered.

One problem faced by all studies of accessibility is defining a meaningful standard of service. That is, what distance constitutes adequate service provision? In transportation planning, for instance, analysts consider a neighborhood served by public transport if it is within a quarter mile (400 m) of a bus stop (15). When siting emergency warning sirens for tornadoes, sirens are

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considered to service an area based on their ability to be heard at a specific distance, ranging from 3,000 to 5,000 ft (16). In dentistry, although federal criteria exist to designate a dental shortage area (17), and states have sought to identify unmet needs (18), no clear geographic service standards exist within these discussions. If people are not near or accessible to dentists, it is more burdensome for them to reach the care they need.

GIS and Spatial Analysis in Health Service Provision. Geographers and health service researchers have long been interested in the spatial analysis of epidemiological and health-related phenomena (19-23). The term "spatial analysis" refers to the analysis of problems with a geographical dimension. However, the role of GIS and spatial analysis in health service provision and accessibility is an emerging field.

The development of GIS has had wide implications for community-based health services planning. It has been used to estimate service areas for health facilities, as well as create spatio-demographic summaries of patients (24); to develop an index of underserved localities in Australia (25); and to conduct a GIS-based analysis of accessibility to primary medical care in rural Colorado (26). Residents' distances to the nearest primary care physician are calculated to estimate caseloads for each physician, where it is assumed that people visit the nearest service provider (26). Generated statistics show that 99 percent of rural Colorado residents are within 30 miles of a general physician. Hyndman et al. use GIS to analyze accessibility to health care facilities in Perth, Australia, including distances patients traveled to have surgery performed (11).

In more model-oriented research, Walsh et al. use network analysis techniques integrated with GIS to model patient flows to hospitals (27). A location-allocation model framework was employed to examine relationships between patients' needs and hospital locations. Oppong and Hodgson also employed a location-modeling framework to assess regional accessibility to health care facilities in Ghana (19), showing that reorganizing existing health care facilities will satisfy accessibility needs and that creating new facilities is not needed.

Although dentistry also deals with care facilities and patient locations, virtually no geographic analyses of dental services have been undertaken. Therefore, there is need for further research.

The aim of this paper is to explore geographical dimensions that might affect accessibility to dental care. Specifically, the term "accessibility" is used throughout this research to describe geographical availability of dental services. The analysis focuses on the distribution of dentists in the state of Ohio. This article extends recent research that uses GIS tools to map dentist locations (9) by first identifying geographical inequities in dental provider locations and applying a methodology that could be useful in establishing new dental facilities that are accessible. Similar to other health studies (11) and policy arenas (10,14,15,19), our research proposes to identify geographical inequities in availability to health care services, although here, our focus is dentistry. However, our research aim also proposes a methodology for addressing geographical accessibility that identifies locations with no dental facilities and then indicates the most appropriate locations for new dental facilities needed.

A "location set covering problem" (LSCP) implemented with GIS is examined as a model for accessibility to dental services based on physical distances by defining suitable service standards between potential patients and dental providers. This approach seeks to ensure that every person is within the adopted distance standard from a dentist.

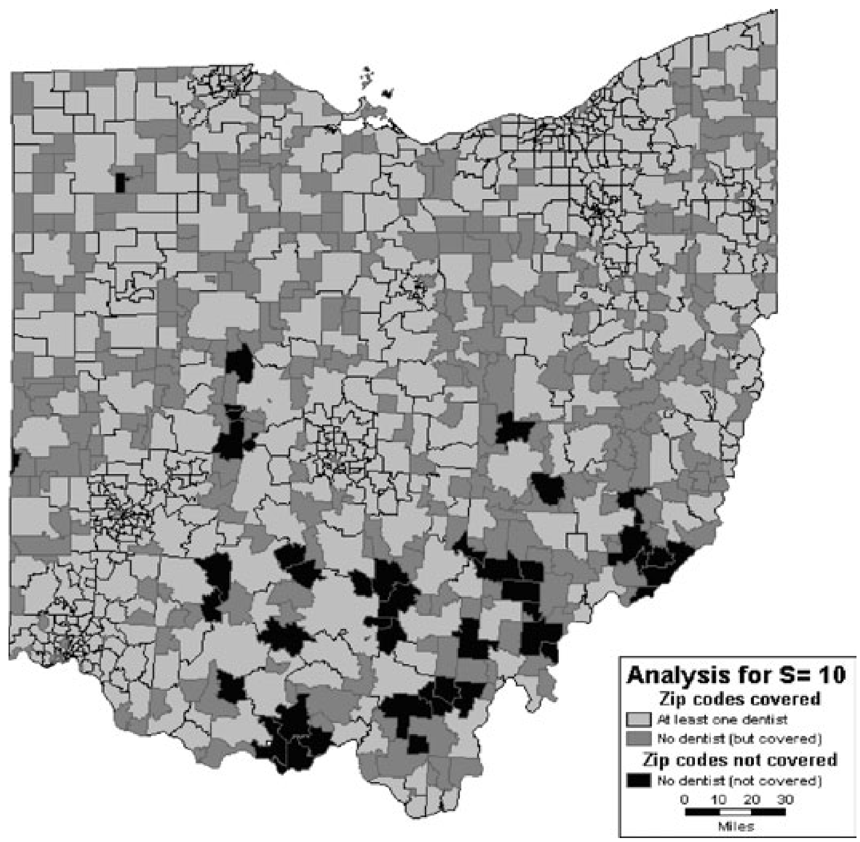
Conceptualization, Data, and Methods

Dentistry and Oral Health in Ohio. Access to dental care in the state of Ohio is not much different than that of the United States as a whole. Analyses of the Ohio Family Health Survey demonstrated that unmet dental needs were the highest of the reported unmet health care needs among adults and children in Ohio (18). Further, minorities, the poor, the uninsured, and persons in relatively poor health experience the greatest barriers to health care, including dental care (18). A previous study of Ohioans showed that low-income people particularly have difficulty in finding dentists who will treat them or their children, and these persons frequently have to travel significant distances in order to receive the care they need (7).

Database of Ohio Dentists. A database of all dentists licensed to practice in Ohio in 1998 was obtained from the State Board of Dentistry. These data are described in great detail by Susi and Mascarenhas (9). The data set contains 6,132 dentists, including general dentists and specialists. Prior analyses of these data demonstrated the dentist to population ratio for poorer Appalachian counties in 1998 was 1:3,146, whereas in metropolitan counties the ratio for the same year was 1:1,479. Overall, for the state of Ohio the average ratio was 1:1,836. Susi and Mascarenhas' (9) findings suggest a dilemma for dental service provision in Ohio.

Information on or addresses of office locations was contained in the database, allowing geocoding of provider locations. There was not complete street-level address information available for each record. However, zip code information was present and, therefore, this was the geographic unit for matching. Geocoding involves assigning dentists' primary office locations to zip codes based on reported addresses. Practices with multiple dentists would have each of their dentists matched to the same zip code. It is important to point out that as a spatial unit, zip codes are not aggregates, or partitions, of commonly used US Census spatial units such as block groups or census tracts. Therefore, the data are not spatially compatible with information captured at those levels. Operationally, the geometric centroid of zip codes are used to represent the point to which dentists are assigned. There are 1,008 zip codes in the state of Ohio.

Figure 1
Zip codes failing the 10-mile standard



A Standard of Availability for Dental Services. Although governing bodies would generally like for all populations to be accessible to dental care, limited standards exist with which to determine whether or not needs are being met. This is in contrast to other planning-oriented literatures where clear service standards are described in terms of a reasonable distance at which facilities are considered to be accessible (15,16).

In 1993, the Health Resources and Services Administration (HRSA) published criteria to be used in determining geographical shortages of dentists. These criteria are based on county-level geographical data and suggest that adequately served areas will have travel times to dental services of 40 minutes or less (17). Unfortunately, county-level data are very coarse geographical units as they mask variation in dental office locations, which are not evenly distributed across a county. An alternative approach is to use more resolute geographical units that cover less land area on a per-unit basis. In this fashion, subdividing the county into several smaller spatial units allows the geographical detail in dental service locations within the county to be more fully understood. Although the HRSA criteria discuss "travel time" as a metric for measuring dental service shortages, we use distance as the basis of our analyses. The geographical approach in this study is defined as a service standard based on distance.

Suppose all zip codes (or patients) in Ohio must be within S miles of a dental provider. If we arbitrarily pick $S = 10$ we can map the zip codes that are not within 10 miles of a dental provider (i.e., within 10 miles of a zip code containing a dentist). This query is easily implemented and handled by GIS. TransCAD GIS v.3.2 (Caliper Corporation, Newton, MA) is used to generate the answer to our query. Based on our chosen service standard, S, Figure 1 maps geographical need for dentists, by zip code. The map points to areas of Ohio that are not served by dentists, particularly the southeastern portion of Ohio, the Appalachian region, which is generally less affluent and less well off socioeconomically than the rest of the state. However, the number of unserved locations will depend on choice of S. For more conservative values of S ($S < 10$), the GIS query will identify additional unserved areas. Conversely, if the distance standard is increased ($S > 10$), fewer zip codes will be unserved.

If the map in Figure 1 showed Q zip codes that were not served by an existing dentist as reported in 1998, governing bodies would likely seek to locate dentists in these areas. But, would the analyst need to recommend locating dentists in all Q zip codes? If there are clusters of zip codes not served by dentists, it may be possible to locate a dentist to serve multiple zip codes, provided the accessibility standard of S miles is met. This would entail locating a number of dentists, X, where $0 \geq X \geq Q$. The idea is to use a strategy that efficiently assigns dentists to improve accessibility, given that there are likely to be spatial clusters of zip codes that are unserved (as illustrated in Figure 1).

LSCP. GIS can be used to identify areas or locations that are not served by the existing geographical distribution of dentists based on a service standard (or standards) for dental accessibility. After demarcating served areas, an approach is needed for determining how many more dentists are needed to serve the remaining unserved areas or locations and efficiently allocate additional dental facilities or dentists to the unserved locations or areas. One could choose to cover all unserved zip codes with dentists, but in many cases this may not be feasible and could be costly. Further, because the set of served zip codes is established through exacting the previously described distance standard *S*, the remaining unserved zips are allocated new dentists in a manner consistent with the means used to identify them at the onset, i.e., using the distance standard *S*. In other words, at the end of the process, all areas need to be served using the same service standard, whether that is achieved through existing dentist locations or suggested new dental locations.

Such a planning scenario can be handled in GIS through application of the LSCP. The LSCP is applied to target locations where dentists are needed. It seeks to cover unserved locations (zip codes) with new dentists. The LSCP is a broadly utilized methodology in spatial analysis, and its variants have been used previously to locate warning sirens (16) and bus stops (15) and to solve many other complex planning problems. The formulation for the LSCP is:

$$\text{Minimize} \quad \sum_{j=1}^{n} x_j \qquad (1)$$

Subject to

$$\sum_{j=1}^{n} a_{ij} x_j \geq 1, \ i = 1, \ldots, m \qquad (2)$$

$$x_j \in (0,1), \ j = 1, \ldots, n \qquad (3)$$

where:

x_j = decision variable to locate dentists office at the j^{th} zip code

a_{ij} = binary matrix describing the coverage of each zip code where

$$a_{ij} = 1 \ \forall i, \ j \ni d_{ij} \leq S,$$
$$a_{ij} = 0 \text{ otherwise}$$

d_{ij} = distance from the j^{th} zip code to the i^{th} zip code

In the context of our problem, the objective function Equation (1) minimizes the number of additional dental offices needed to provide accessible care to unserved zip codes. Equation (2) describes constraints that ensure all previously unserved zip codes are covered by at least one new dentist office based on a service standard of *S*. Equation (3) imposes binary integer restrictions on the decision variable. That is, a dentist office must be located to a zip code or not; fractional values do not make sense. Essentially, the model treats zip codes equally in that all unserved locations are candidates for new dental offices to be located. Once a zip code is served by at least one dentist based on the pre-specified geographical service standard, the model considers the area satisfied. Running the LSCP points out a subset of zip codes from the set of currently unserved locations in which dentists should be located to serve *all* unserved zip codes. The primary variable to be manipulated in this analysis is the choice of service standard *S*.

Results

From the initial set of 1,008 Ohio zip codes, 413 were identified as not having a dental office located within them (Figure 1). LSCP was solved for varying dental service standard definitions: *S* = 5 (all zip codes with no dentists must be within 5 miles of a zip code with a dentist) to a high of *S* = 15. At *S* = 5, there were 305 unserved zip codes, with offices needed in 253 of the zip codes. Conversely, at *S* = 15, almost all zip codes in Ohio are served by the existing configuration of dentists (only two unserved zips remain). The solutions to the LSCP for *S* = 5 miles to *S* = 15 miles are displayed in Table 1.

Several key observations are made from Table 1. First, as *S* increases, the number of unserved zip codes to address decreases. As we employ larger service standards, unserved zip codes are more likely to be covered by current dentist locations in adjoining or proximal zip codes. Second, once we apply *S*, a subset of zip codes from the set of 413 zip codes with no dentists is established. The results of the LSCP solved for these subsets of zip codes indicate that always *fewer* dentists are needed to cover unserved locations. Therefore, locating a dentist at each unserved zip code is not needed. The reason for this is that unserved areas are usually clustered spatially. This is evident in Figure 1 where unserved locations based on *S* = 10 tended to group around the southeast region of Ohio. Third, there is a wide range of need based on these results. At *S* = 5, the LSCP must deal with 307 unserved zip codes, almost a third of the zip codes in Ohio. If we increase *S* to 8, the

Table 1
Results of the Access to Dental Care Analysis Based on the Location Set Covering Problem (LSCP) Modeling Technique*

Trial	Service standard (miles)	Unserved zip codes	Offices needed
1	5	307	253
2	6	247	173
3	7	185	109
4	8	126	76
5	9	84	50
6	10	45	24
7	11	23	14
8	12	16	9
9	13	11	8
10	14	4	4
11	15	2	2

* There were 11 separate applications of the LSCP. In trial 1, for example, a service standard of 5 miles was applied. It was found that 307 Ohio zip codes were not served by a dentist or a dental office (i.e., they were not within 5 miles of another zip code having a dentist/dental office). Based on this standard, 253 zip codes would need to have dental offices in order to cover the unmet demand.

number of unserved zip codes is more than halved (126), demonstrating that S is sensitive to definition.

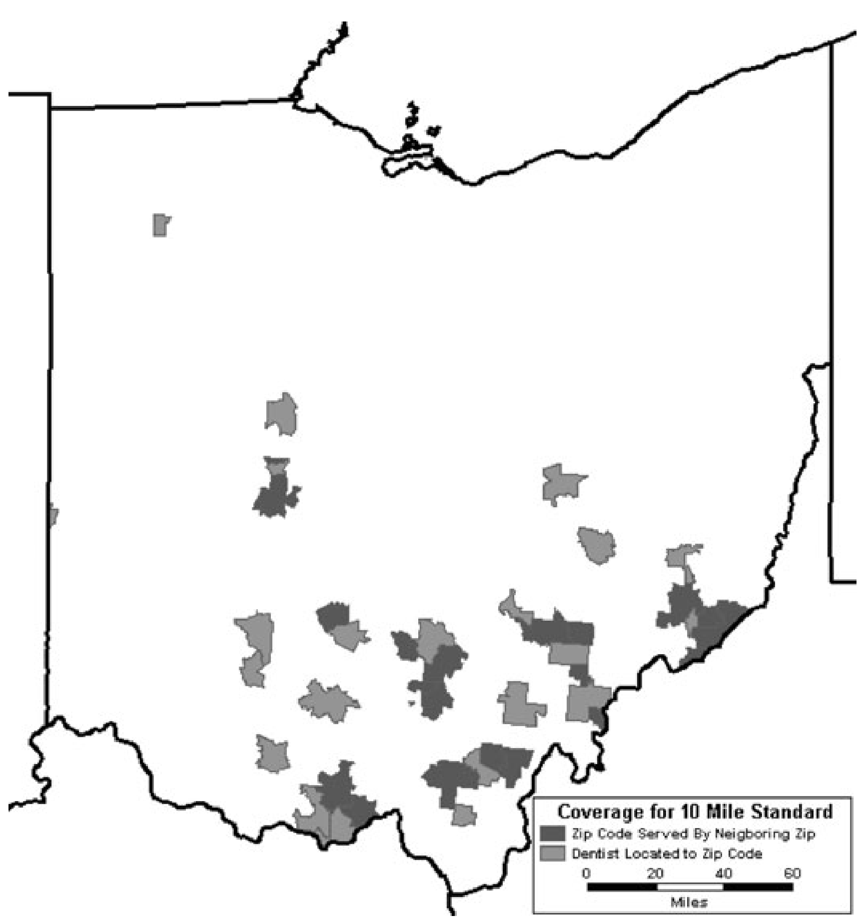
To further illustrate the meaning of these results, consider $S = 10$. In Table 1, if $S = 10$ then 45 zip codes in the state of Ohio are not served by dentists. In order to serve these 45 zip codes, we solve the LSCP and find that 24 additional offices need to be located. The exact configuration of the needed offices for $S = 10$ is displayed in Figure 2. The map in Figure 2 shows that new offices can be strategically positioned to serve nearby unserved zip codes. Allocating new offices to these zip codes would allow, in the broadest sense, every individual in Ohio to be within 10 miles from a dentist.

Discussion

Dental care and its availability to populations are important to achieve or maintain optimal health. Building on past studies that have explored the role of geography in the dental access question (9), this article presented an analysis of geographical accessibility to dental services in Ohio. Our focus was specifically on a) better understanding the variability in dental locations and b) demonstrating a method that can suggest needed improvements in the distribution of dental locations. Our approach allows interested researchers and policymakers to explore service and geographical accessibility issues in the field of dentistry.

This research is most appropriately described as developing a stand-alone tool that looks at one particular dental access issue: that of geographic location. It is meant to supplement ongoing research that considers different and perhaps more comprehensive definitions of access.

Figure 2
Solution to the $S = 10$ problem



Results of an analysis of Ohio demonstrate the potential need for new dental offices throughout the state. Geographic need, as it has been explored here, is sensitive to service standard definition. In our work, as there exists no standard such as the National Committee for Quality Assurance standard in medicine as to what constitutes an acceptable service standard in dentistry, several definitions of coverage were tested, facilitated by the flexibility of the GIS-based modeling environment. No matter the coverage standard chosen in this analysis (Table 1), some areas or zip codes emerge as being unserved in Ohio. The map in Figure 2 shows that many of the unserved zip codes are located in Ohio's Appalachian corridor. Earlier work by Susi and Mascarenhas points out that higher dentist to population ratios were found in this area (9).

As governing and policy bodies plan, they should consider the concept of geographical accessibility, e.g., developing programs in Appalachia. As policy, it may be the case that governing bodies would encourage beginning dentists to set up practice in unserved or underserved locations in exchange for some or all of their dental school tuition or loans being forgiven. Our approach to delimiting unserved areas could contribute to such strategic planning.

Other methods have been used to identify underserved areas based on geographic considerations. One is the HRSA criteria for designating dental shortage areas (17). These criteria are: a) the area is a rational area for the delivery of dental services; b) the area has a population to full-time-equivalent dentist ratio of at least 5,000 : 1, or the area has a population to full-time-equivalent dentist ratio of less than 5,000 : 1 but greater than 4,000 : 1 and has unusually high needs for dental services or insufficient capacity of existing dental providers; and c) dental professionals in contiguous areas are overutilized, excessively distant, or inaccessible to the population of the area under consideration. It is clear that our study differs substantially in that we focus exclusively on geographical access. Thus, in future studies, it may be appropriate to use GIS and other spatial analysis techniques to explore other aspects of how the HRSA criteria delimit need in certain locations.

Many other opportunities exist for the enhancement of our efforts. We structured our model quite generally, so we could focus developing the basic methodology itself. First, we adopted straight-line distances between zip code centroids when determining service, as it has been done in other research (10,15). This was done because accurate distance calculations may be performed in a straightforward manner using GIS. It should be pointed out, however, that it is possible to incorporate more complicated measures of the separation between locations into spatial analyses, such as travel time based on road networks (28). Choice of distance metrics likely has implications for analytical results, which should be explored in a future study (28). Second, it is important to consider the population density of zip codes themselves when deciding which areas receive coverage. Here, we structured our analysis such that dentists either covered zip codes or not. Methods exist in the literature that allow explicit consideration of population when making locational decisions (16,19). Many other issues that are important in the discussion on dental access could also be explored in future analyses, including insurance coverage – accepting patients with Medicaid insurance and hours worked by dentists.

In terms of its limitations, the approach presented in this article is just one tool that may be used to address access issues of a geographic nature; it focuses on a specific definition of location. In sum, we hope our work contributes to building bridges between the health policy, dentistry, and medical geography, communities, and that our approach might be considered in future examinations of dental access.

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