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Multiobjective Location Planning for Primary Medical Services in Rural Iowa

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ABSTRACT

Developing location plans for primary medical services is a multiobjective location problem. In rural regions, plans must consider both the ability of a location to retain needed health care professionals and the accessibility of service center locations to the rural population. Using township level population data and a model of physician attrition, these objectives were incorporated into a location-allocation model and applied to rural Iowa.

INTRODUCTION

This paper discusses part of a planning study to identify optimal locations for providing primary medical and dental services to rural Iowa. The study was prompted by several factors. First, rural areas of Iowa had few primary care practitioners, and these were not uniformly accessible to the population. In addition, many rural practitioners were old and terminating practice; a large proportion could be expected to retire or die in the near future. Many of the smaller communities had been unsuccessful in their efforts to recruit younger practitioners, and to retain those successfully recruited. Iowa shares these characteristics with other states. A high proportion of its population is rural, however, living at low to moderate densities, and the proportion of its population that is older than sixty five is one of the highest in the United States.

The planning study had two objectives. One was to explain and predict the attrition of physicians and dentists in rural areas. The major findings of this part of the study may be found in Henderson, Kohler, and Meneley (1) and in Henderson and Meneley (2). The second objective, and the one on which this paper focuses, was to use the understanding of the attrition process to help identify sites to ensure future access to primary medical and dental services in rural areas. The strategy was to develop a plan that could meet the increasing rural demand for accessible primary care with minimum intervention by the State of Iowa. It was expected that the state and regional health planning agencies would designate sites, encourage their development, and give nonmonetary assistance to them, but that it would not hire staff, contribute buildings or equipment, or deliver public medical services beyond those it was already providing, such as examination of children for potential cardiac problems.

The first part of the paper presents more detail on the background and assumptions of the study. These led to the specification of objective functions for a location-allocation model. The remaining sections discuss this model, its implementation in the Iowa study, an algorithm for solving it, some results, and an issue that arose during the analysis and that remains unresolved--that of different preferences for attributes of location patterns at different geographical scales of analysis.

BACKGROUND

The number of physicians and dentists in rural areas has been decreasing. As practitioners leave small communities for larger ones, and as older practitioners die or retire, they are not being replaced at the same rate. The results of this attrition process has been a smaller number of physicians and dentists in rural areas, a decrease in the number of communities offering medical and dental services to the rural population, and a decrease in physical accessibility to primary medical and dental care. For example, 437 communities in Iowa had at least one primary care physicians in 1960, but this had fallen by 19.7% to 351 communities in 1972 (1). For primary care dentists, the corresponding figures were 320 and 267 communities, for a decrease of 16.6%. During this time, the rural population of the state

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(in communities under 25,000 population) remained constant, at 1.811 million people. As the number of towns providing service decreased, the average distance to the closest practitioner increased. For those people in Iowa without a local primary care physician, the average distance increased from 10.56 kilometers in 1960 to 11.70 kilometers in 1972, an increase of 10.8%. For primary care dentists, the increase was from 12.28 km to 13.24 km, or a 7.9% increase.

From the perspective of the rural community that is losing its physician or dentist, and from the perspective of regional health services planning, the challenge is to attract new practitioners into rural areas and to retain them once they are there. At least part of the difficulty in recruiting younger health care personnel in rural areas can be linked to conditions of rural practice. In the past, primary care physicians and dentists have had solo practices. In rural areas, this means being the only practitioner in the vicinity, being on call at all times, having long, odd hours, and having difficulty in planning or taking leisure time. It also means relative physical isolation from ones colleagues and their experience, less professional interaction, lower accessibility to specialized facilities and staff for diagnostic tests and, usually, few of the cultural amenities desired by highly educated people. Some of these conditions can be improved by entering group practices with other practitioners. Properly organized, a group practice permits sharing and scheduling of work and, if large enough, it can meet some of the need for interaction and consultation with colleagues and access to some specialized equipment such as x-ray equipment and technicians. Group practice alone, however, will not satisfy the desires of physicians and dentists for ready access to hospitals and specialized practitioners to which patients may be referred, or to urban cultural amenities. Moreover, favoring group practice as a strategy for providing primary care in rural areas raises three issues.

First, an emphasis on group practice alone conceivably could reduce rather than increase the accessibility of health care to the rural population. As a practice acquires additional staff and equipment, it requires a greater level of patronage to survive. If rural population, income, and use rates remain constant, the need for greater patronage implies fewer practices serving larger areas with longer maximum and average travel times for the consumer.

A second issue is that of the resources required. A small group, containing perhaps three or four physicians and an appropriate amount of support staff may require little more equipment per practitioner than a solo practice. If the group is much larger, however, it may permit greater specialization of staff and equipment, even when its principal objective is primary care. For example, the staff may include an obstetrician, gynecologist, pediatrition, or radiologist, and this staff may require more laboratory or x-ray equipment if it is to be productive. With increasing concern over health care costs and duplication of resources, it makes sense for larger groups to consider locating in rural communities that already have some of these resources in small hospitals, rather than trying to duplicate them in other locations. In addition, it makes sense to consider groups of different sizes. Smaller group practices, located in areas with few resources, would provide individual services but would refer some patients to larger groups or to more specialized secondary care centers, rather than attempting to provide the comprehensive services that require a larger group.

A third issue is that establishing a new group practice is a cooperative, interactive effort. It requires that several practitioners be aware of a location, its potential, and the possible interests of other practitioners at the same time. Again, as the size of the group practice increases, the amount of information involved also increases. Once the group has been established, however, the information necessary for recruiting a new member may be little more than that now involved in recruiting a solo practitioner.

The planning study considered the first two issues in a location-allocation model. One objective function used in the model was to maximize accessibility, and another was to maximize the use of existing medical resources. During the course of the study, the concept of the type of center being located changed several times, but the predominant view was that they would tend to be fairly large groups, involving primary care physicians and dentists, as well as nutritionists and other health care professionals. It was expected that they would be closely associated with and supportive of a community hospital. Smaller practices, including solo as well as small groups, would exist in smaller communities surrounding the larger regional primary care centers; they were expected to develop as needed but on their own, however, and they were not explicitly considered within the location model. The third issue, that of information, was not considered in the study, but as will be seen shortly, the study developed an information system that can be queried by practitioners seeking new rural locations.

MODEL

The location-allocation model used can be stated as a variation of the p-median or central facilities location model (3) as follows:

$$\text{minimize } z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}x_{ij} \qquad (1)$$

$$\text{subject to} \quad \sum_{i=1}^{n} x_{ij} = 1 \qquad i = 1,2,\ldots n \qquad (2)$$

$$x_{jj} - x_{ij} \geq 0 \qquad i = 1,2,\ldots n;\; j = 1,2,\ldots n;\; i \neq j \qquad (3)$$

$$\sum_{j=1}^{n} x_{jj} = p \qquad (4)$$

$$x_{ij} \geq 0 \qquad (5)$$

where n is the number of locations in the problem, p is the number of centers to be located, i is a place to be served, j is a candidate for a regional primary care center number of centers to be located, x_{ij} is the decision variable set, and c_{ij} is a coefficient defined to reflect accessibility and resources. To define the objective function (1),

$$c_{ij} = w_i d_{ij} \qquad i \neq j \qquad (6)$$

$$c_{ij} = -kr_j \qquad i = j \qquad (7)$$

In this notation, w_i is the population of community i, d_{ij} is the distance from community i to community j, r_j is a score reflecting the health resources at community j, and k is a weight used to vary the emphasis given to accessibility and resource use. Increasing $|k|$ causes the model to select locations that increase the use of local resources and decrease accessibility.

IMPLEMENTATION

The study used a data base containing 2,446 locations in the state of Iowa and an additional 544 in counties of states adjacent to the Iowa border. These locations were U.S. Census enumeration districts (EDs) in rural areas, and aggregations of EDs in incorporated settlements. Except for very large cities, such as Des Moines, Cedar Rapids, and the Quad Cities area, the locations represented areas no larger than a civil township (93 km^2, or about 9.6 km across). Associated with each location was a pair of Cartesian coordinates; socioeconomic data from the fifth count of the 1970 census; population from the 1960 census (disaggregated from 1960 minor civil divisions to 1970 EDs); medical and dental manpower including type of practice and employment situation; and hospital type and facilities. Manpower data was collected for 1960, 1967, and either 1972 (for physicians) or 1973 (for dentists). A complete description of all data sets developed for the study can be found in reference (4).

The data base could be entered at any location and, using distances computed between locations from their coordinates, organized spatially to yield service areas for solo or group practices and measures of accessibility between locations. These groupings and measures were permitted to cross state boundaries, just as visits to physicians and dentists do. Using these features, the population or other characteristics of service areas were easily computed, as was accessibility of any location to its nearest physicians, dentists, hospitals, or large cities. These locational variables were then available for use in the analysis.

The location-allocation model requires a measure of primary health care resources at each candidate location. In consultation with health planners, the research team derived an index of resources, composed of five equally-weighted variables: the number of primary care physicians under 60 years of age in the place; the occupancy rate of the hospitals in the place computed from a poisson function relating occupancy to hospital size; the population size of the place; a statistical measure of the probability of gaining or not losing primary care physicians in the place; and the ratio of the population to the number of physicians in the local area. Research done during the first phase of the study as well as work in central place theory, had demonstrated the importance of local community population as a base of patronage, and had derived the probability of gaining or not losing physicians from a discriminant analysis of towns that had gained, lost, or held even in number of physicians between 1960 and 1972 (2). The population-to-physician ratio was used a measure of a readily available market for primary care. Each variable was standardized from zero to one, using a different scaling function. The functions and the list of scores for 381 communities in Iowa appear in (5). The index predicts the occurrence of other health services reasonably well. When communities with scores greater than a critical value were assumed to have a service while the remainder did not, the scores correctly classified 75 per cent of all communities with respect to emergency ambulance services, 72 per cent for nursing care centers, and 90 per cent for optometrists.

Although the data base contained 2,990 places in and around Iowa, it was not realistic to consider all of them as candidate locations for regional primary care centers. Aside from the technical problems of problem size, most of them were either purely rural or too small in population to be viable locations for such a high order service. The candidates were chosen to include all places in Iowa with acute general care hospitals; the top half of the communities with primary care physicians, based on the resources score; and, where necessary, communities chosen to ensure at least one candidate in each county. Of the resulting 210 places twenty-three had populations greater than 10,000 and the level of service anticipated for the largest regional primary care center. These places were assumed to occur in all solutions generated for the problem. In addition, seventeen places in the counties surrounding Iowa were providing a high level of primary care and were assumed to be in all solutions, and six candidate locations were selected in these contiguous counties, based on estimates of their resources. The resulting problem was to serve the 2,446 locations inside Iowa from the 233 candidates inside and outside the state, 40 of which were assumed to provide the service already.

Although this is an extremely large problem, it can be made much more tractable by applying simple principles. The size of the problem is in part a function of the problem, the number of distances in candidates, and the number of centers. The number of distances can be reduced sharply if there is a distance beyond which no travel will occur, because these greater distances in effect are all equal and infinite. The assumed maximum distance was 88.5 km (55 miles), which is clearly greater than Iowans would consider driving for primary care, and clearly greater than needed if at least 55 regional care centers were to be located within the state. A second principle for reducing the number of distances used the twenty-three assumed centers within the state. For example, when a community was 16 km from one of these centers, it would never be necessary to consider distances from this community to other candidates more distant than 16 km, because they could never be more accessible than the assumed center. Again, the ignored distances can be assumed to be equal and infinite. A file structure was developed and programs were written to take advantage of these principles (6)(7).

SOLUTION

Even after reducing the problem size in the manner described above, the size of the problem still required heuristic solutions. The vertex substitution algorithm of Teitz and Bart (8) was used to find the patterns that minimized average distance to the nearest regional center, and the plans that maximized use of available resources were found by sorting the candidates according to their index value scores. To find compromise plans between these extremes, the vertex substitution algorithm could have been used without modification, operating on the problem formulated in equations 1-7. Instead, the research team modified the algorithm and problem formulation, in an attempt to simulate the way that a group of health planners made changes to some of the most accessible location patterns. The resulting algorithm is unconventional and too long to describe in detail here, but it has been described fully in (5)(7). The most significant feature of the modified algorithm is its recognition of the possibility that decision makers may evaluate plans at two scales more or less simultaneously. At the "global" or state scale in the Iowa example, health planners may be concerned with comparing plans using statewide averages for accessibility and resource use. At a more local scale, however, perhaps involving three or four counties, they may be concerned with purely local differences, within some broad limits imposed by the statewide problem. Measurements of the local and global differences, gains, and losses incurred by moving a center may be made using different measurement scales for the same variable, or even different variables entirely. The modification of the vertex substitution algorithm attempts to capture the spirit of this type of evaluation process, although the precise form of the process is not well understood.

RESULTS

The model was used to identify thirty location patterns: one with high resource use, one with high accessibility, and one a compromise for each of ten numbers of centers, ranging from 55 to 102 in increments of four or five. The patterns with 55, 64, 68, and 72 centers were of greatest interest. For the 55-center case, moving from the most accessible pattern to the one relying most on local resources led to an 8% increase in the average distance to the nearest center, but to a 6% gain in the average scores of communities with centers. These percentages decreased, although not monotonically, as the number of centers increased. The compromise patterns generated with the modified algorithm all had average distances within .6% of those in the most accessible patterns, and average resource scores only 1-2% less than the averages in the patterns that emphasized resource use. Attempts to find compromise patterns with smaller differences in average resource scores led to increases in average distance that were not considered acceptable. These are statewide averages, and they mask much larger percentage differences in the northeastern, southwestern, and south central parts of the state. With the exception of only one center, increasing the number of centers in the compromise patterns occurred by adding centers, not by relocating them. The reason for this stability requires further investigation, but it appears to be a result of the large number of centers and the use of place specific resource scores.

The results indicate a well-behaved problem, in terms of both the shape of the noninferior set and the ability to start with the smallest number of centers and retain optimality during its expansion. The research team recommended that the compromise pattern for 55 centers be developed, and that serious attention be given to expanding the system to the 68-center compromise.

CONCLUSIONS

This research raised a large number of issues, only a few of which have been mentioned here. From the location-allocation modeler's point of view, the stability of the problem and its relationship to place-specific scores require further research. The possibility of evaluating patterns simultaneously using local and "global" criteria needs to be considered in a much more rigorous fashion; the choice of scales for evaluation is, itself, a multiobjective problem.

From the geographer's perspective, perhaps the most important issue is that of the need for interaction between location theory and location-allocation modeling. In the case of service centers, central place theory should provide a guide to a number of practical modeling problems, particularly if the analysis covers a large region in great spatial detail. Location-allocation modeling, however, can contribute to the development of theory by operationalizing fuzzy concepts, by permitting analyses of real landscapes in addition to geometrical simplicity, and by suggesting new questions that the theory has not yet addressed adequately.

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