AN OPTIMIZATION MODEL FOR HEALTH CARE RESOURCE PLANNING IN NORTHEAST NORTH CAROLINA

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ABSTRACT

This research looks at the problem of remoteness and accessibility of healthcare services for the at-risk population who reside in the designated distressed counties of northeast North Carolina including Bertie, Gates, Halifax, Northampton, Perquimans, Tyrrell and Washington. The geography of these distressed counties is such that it hinders the development of healthcare facilities that are economically viable and that can respond adequately to meet the needs of the at-risk population. Without an optimal spatial distribution of healthcare facilities in harmony with the distribution of demand, greater travel efforts are required, imposing a burden on the meager resources of the at-risk population. To arrive at an "optimal" solution, a facility location and resource allocation model is utilized. The routine employed for the location/allocation optimization model is based on algorithms used for solving the p-median or min-sum multi-center network design problems. Data collection from various databases is currently underway with an anticipated completion timeline of nine to ten months.

INTRODUCTION

Health care planners and public policy makers are searching for new approaches to delivery of healthcare services that will simultaneously reduce costs and improve access. In light of this, a public-private partnership is often discussed as a vehicle for improving short term and long term outcomes of the health care network. The overall intent of this approach is to promote sustainable community development. Recently, economists of various persuasions have also promoted public-private partnerships (PPPs) as a means of promoting economic growth, per capita income, and social welfare both on a domestic and international scale (Burd and Currie, 2004). Others including the Canadian Community Economic Development Network (2007) see this process as a means of promoting community economic development (CED) where the emphasis is on building community-based enterprises in cooperation with public sector agencies.

Implicit in the idea of community development and resource allocation is a reasoned expectation that healthcare planners and policy makers can add to "Pareto optimality" and thereby maximize community welfare. Health care planners in rural areas must contend with balancing resource efficiency vis-a-vis maximizing community welfare. Since Pareto optimality is more idealistic than practical, Pareto improvement is often the preferred approach. It is based on the idea that distribution of resources over a large number of projects is likely to benefit more constituents than concentrating them in a few locations or in a few projects. Of course, the underlying premise is that resource allocation decisions systemically seek to obtain the greatest benefit at the least cost. This approach, which is the position of many economists, argues that the projects should improve the welfare of society as a whole. Palmer and Torgerson (1999) contend that strict adherence to such criterion is in practice difficult. Consequently and with few exceptions, health care planners in rural areas are being forced to redesign the facilities so that they will be equitably and fairly distributed across the different geographic areas and also provide a high quality of service to the constituents at the lowest possible cost. We need more facilities to provide a high quality service. But the resources are limited and we have to accomplish our goals with the lowest possible cost, which implies that we need to cut down the number of facilities. It is clear that we are dealing with multiple conflicting objectives (Johnson, Gorr, and Roehrig, 2002).

THEORETICAL BACKGROUND

An overview of the literature suggests that integration and aggregation of health care delivery in rural areas can prove to be especially challenging and time consuming. As a result, defining the exact nature of the problem can help us understand not only the rationale of the study, but also the validity of the assumptions essential to a study's underlying purpose. Toward this end, this study is developed with concepts originating in socioeconomic theory and optimization models rooted in graph theory and management science methods. These origins are the basis for the study's analytic inquiry and interpretations. With this approach, there is a greater probability that the qualitative and quantitative aspects of both the spatial and geographic patterns will be reflected in the design of a more efficient and effective health care network. To support this line of reasoning, the inquiry relies heavily on an evaluative process that incorporates several aspects of location and geographic proximity analyses. These lay the foundations from which health care planners can examine the conflicting multiple objectives and formulate policies to obtain optimal solutions

Role of Internet

For rural communities, the problems of remoteness and access are acute because spatial consequences matter, even when transportation costs are zero and knowledge is assumed to travel across space freely. In other words, without adequate access to internet technologies (knowledge), at-risk populations may be at a disadvantage merely because of their remoteness. In this instance, social interactions are circumscribed by physical distance and therefore tend to reinforce strong offline social ties among clusters of underserved participants. On the health care provider side of the market, internet technologies also play an important role, since providers have to consider internet-based technologies as a part of their criteria in location decisions. Hence, assuming adequate access to internet-based networking technologies, one might reason that knowing more can pay off for all participants, especially with respect to education enrichment afforded through a structure of relationships similar to that suggested by Putnam (2000). Ostensibly, this appears to be a significant ingredient for a more effective and efficient health care network, especially as it relates to reallocation effects in a rural health care network with inherent spatial distribution related inequities.

From the viewpoint of the health care network, one can reason that health care-seeking household/individuals on the demand side (i.e. preferences with a social component) and health care providers on the supply side of the market (i.e. technology in a knowledge-rich environment) are highly dependent on internet-based knowledge and information as a basis for participation and allocative efficiency. Thus, awareness of and access to internet-based knowledge in an environment of education and personal responsibility is critical for health care planners in minimizing health care costs. Without sufficient attention of planners and policy makers to these effects, future outcomes especially in rural underserved areas remain in a state of uncertainty. For that reason, there is an apparent likelihood that the implications for decision and policy makers will continue to require multi criteria considerations.

Although a knowledge-based infrastructure can to a large extent mitigate problems associated with accessibility and remoteness, it does not alleviate the challenges faced by planners and policymakers concerning the optimization of the physical location of facilities in conjunction with the distribution of demand and travel requirements. As a result, physical location of facilities and a knowledge-based infrastructure are complements and are increasingly becoming mutually supportive in an optimized healthcare network. In this research, there is an attempt to recognize and incorporate such mutual dependency.

Graph Theory

In the social sciences, optimization models based on graph theory have been used as a means of expressing the relations in social networks, which can also integrate the concept of location proximity. These include research on the interactions between individuals and also the interactions between groups and how these interactions affect location proximity and resource allocation. Another example based on graph theory can be found in engineering network theory and related mathematical concepts where a network is defined as an entity with vertices or nodes connected by lines or edges. The study of network flow models is crucial to understanding the health care network as a configuration of routes connecting various locations through which people/services move. Network-based optimization models are some of the most utilized techniques in operations management and serve as a basis for decision support systems in the private sector.

Problems of this sort can be illustrated by utilizing a network of arcs and nodes. Business operations in a distribution network comprising warehouses, delivery points, connected by various roads are good examples. In primitive form as defined in mathematics, engineering, and the sciences, a network is nothing more than a set of nodes connected by arcs or lines. In high level networks such as the health care network, these concepts can be illustrated utilizing applications of graph theory where compilations of nodes (vertices or locations) together with arcs (links) connect to form an application of location theory. As a graph (Diestel, 2000), the health care network can be described as an undirected (connected) graph where $G = (V, E)$ and the set V of vertices (locations) is the set of all locations and the set of edges E (lines) coupled with some value (weight or distance) that connect the locations (Hoelting, Schoenefeld and Wainwright, 1995)

LOCATION THEORY AND OPTIMIZATION

Many geographical locations lack the necessary facilities to support the needs of the at-risk populations, which creates the necessity to travel to another location in order to gain access to a desired service (Kaiser, 2000). The travel route becomes the edge in the terminology of Graph Theory. Edges can also have varying degrees of distance...say the distance between two locations A and B (health clinics) in a geographical sense. From an allocation perspective, one can assume a set of locations in V from which every other location in V is covered or alternatively an optimal location where the at-risk household/individual is assigned to the nearest facility.

Since problems of this type decide the location of facilities and allocation of the demand points, they are generally referred to as location-allocation problems, and the healthcare network design problem falls in the class of problems known as the $p-$median problem. More specifically, the $p-$median problem belongs to a larger class of problems referred to as min-sum location-allocation problems that can be further distinguished as the $p-$center problem (Hakimi, 1964) and the $p-$median problem (Hoelting, Schoenefeld and Wainwright, 1995). Our primary focus here is the $p-$median problem. Fundamentally, the $p-$median problem determines p facilities in a predefined set of V with $m\,(m > p)$ candidate facilities. The goal is to minimize the Euclidian distance (or some other linear function of distance) between each demand point and its nearest facility. From the point of view of the healthcare network, the goal is to identify the locations that provide greatest access to the n demand points (vertices) where clusters of the at risk population reside (Kaiser, 2000). Each of the p points selected serves as a health care facility where each of the n vertices is served by one of the p service facilities located in the network. The optimal set of p points will minimize the sum over all vertices of the path lengths from a vertex to the nearest health care facility (Hoelting, Schoenefeld and Wainwright, 1995).

In this case, the assumption is that edge cost is expressed as the weighted Euclidean distance where health care centers p are necessarily points in the set V. Total cost is established by summing the weighed distances from each vertex to each of the healthcare facilities. These problems belong to a class of optimization problems (more precisely Integer Programming Problems) involving 0-1 variables where a value of one indicates that a facility is selected and a value of zero indicates that it is not. An added advantage to this approach is that they can accommodate numerous variables making them almost ideal for solving facility location problems involving several potential site locations. If there are, for example, thirty potential locations, then there are thirty decision variables in which a decision must be made for each potential site (Stevenson and Ozgur, 2007).

Formulation of the Healthcare Network Problem as a p-Median Problem

The task is to ascertain locations for a given number of service facilities that will satisfy the demand when the spatial distribution and the demand (user, at-risk population) at a particular point are known. To describe the $p-$median problem, a set of linear constraints and a linear objective function are utilized. Fundamentally, the mathematical formulation of the $p-$median problem can be summarized as follows (ReVelle and Swain, 1970):

$$\text{Min} = \sum_{i=1}^{m}\sum_{j=1}^{n} w_j d_{ij}\ x_{ij} \qquad (1)$$

Subject to:

$$\sum_{i=1}^{m} x_{ij} = 1 \qquad j = 1,2,\ldots,n. \qquad (2)$$

$$x_{ij} \le y_i \qquad \forall i, j, \qquad (3)$$

$$\sum_{i=1}^{m} y_i = p, \qquad (4)$$

$$x_{ij} = 0 \text{ or } 1 \qquad \forall i, j, \qquad (5)$$

$$y_i = 0 \text{ or } 1 \qquad i = 1,2,\ldots,m. \qquad (6)$$

Where:

n Total number of demand points,

m Total number of potential sites,

x_{ij} 1 if demand point j is assigned to facility located at point i, 0 otherwise,

y_i 1 if point i is allocated as a facility, 0 otherwise,

w_j Demand at point j,

d_{ij} Distance from point i to point j,

p Desired number of facilities to be located.

In the optimization process various configurations can be generated with each configuration having exactly p facilities. Each such configuration also provides a feasible solution to the $p-$median problem. Although at least one optimal solution exists for every $p-$median problem, others can exist if more than one configuration has a minimal cost. The p-median problem discussed above assumes only one type or kind of service facility. However, in practice we may encounter a hierarchical system in which levels of services are managed based on the complexity of service. Solving the p-median problem itself is hard since it belongs to a class of problems known as NP-hard problems (Garey and Johnson, 1979). Here, we will limit our analysis just to one type of service facilities and focus only on the solution of the basic p-median problem

POPULATION DATA AND SAMPLING TECHNIQUE

The research domain chosen for this study includes the rural counties of northeast North Carolina. This region is made up of seven contiguous counties including Bertie, Gates, Halifax, Northampton, Perquimans, Tyrrell and Washington. They are located in an economically distressed area aggravated by lack of economic development opportunities, high unemployment, poor rural populations who contend with inadequate health care services and long-distance-travel requirements. The northeast region is typical of economically distressed rural areas on the margins of financial viability but with potential for significant economic development. The North Carolina Department of Commerce generally defines so-called tier one distressed counties as those in need of economic development. Specifically, several criteria determine the distressed designation. Those include average rate of employment, per capita income and population growth. In recent testimony before a forum presented by the Agency for Health Care Research and Quality, the Director, Office of Rural Health and Resources Development, North Carolina Department, of Human Resources reported that the state's economic poverty is a major challenge. The director presented data that showed that 50 of North Carolina's 100 counties had 40 percent or more of families earning incomes below 200 percent of the poverty line. Even more revealing were the data that all but three of the one hundred counties were rural.

These economic circumstances have been exacerbated by the steep decline in the manufacturing sector and the increasing outsourcing activities of American industry in the past decade. Another factor that has an adverse impact on the at-risk population is the influx of immigrants. According to the Federation for American Immigration Reform, which quotes several studies in a published article "Lower Wages for American Workers", contributes to depressed wages for the underserved population. Currently, these include Bertie, Gates, Halifax, Northampton, Perquimans, Tyrell and Washington all of which are located in northeast North Carolina. Their geographic location is such that they do not have the required health care facilities adequate to support the at-risk population. These counties also constitute a region that has great potential for development because it offers a wide range of location options available to health care resource planners for improving the efficiency, effectiveness and equity of health care delivery.

Since the optimization of health care service locations necessitates highly reliable input data, careful selection of datasets is extremely vital. Kitchin and Fotheringham (1997) found that aggregation can corrupt the solution results of a location problem and decrease the quality of the solution. Others, including Murray and Gottsegen (1997), report stable resolutions with the $p-$median problem, when aggregated data is utilized. Besides, since the $p-$median problem is based on spatially distributed demand values and total population is utilized for demand, it is reasonable to assume that demand can be specified more accurately in most instances. This is particularly the case when travel distance to a service facility can be lengthy and an optimization analysis can provide greater accessibility (Kaiser, 2000). For this study, it is estimated that the data collection and generation of the "optimal" solution will require approximately nine to ten months. Optimization of health care service locations is very sensitive to input data indicating that solving the $p-$median problem requires careful use of datasets especially where data is sparse or missing and aggregated demand data is utilized.

SUMMARY

Some issues related to the accessibility of healthcare services for the at-risk population in the distressed counties of northeast North Carolina are discussed. The geography of these distressed counties is not conducive to the development of economically viable healthcare facilities that can respond adequately for the needs of the at-risk population. The goal of this study is to develop an "optimization" model that would help in the design of a network of healthcare facilities that can be accessible to the at-risk population. To arrive at an "optimal" solution, a facility location and resource allocation model based on the algorithms used for solving the p-median or min-sum multi-center network design problems is utilized. Data collection from various databases is currently underway with an anticipated completion timeline of nine to ten months.

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