DETERMINING LOCATIONS FOR RURAL MEDICAL CLINICS: A MODEL AND ITS USE*

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INTRODUCTION

One of the nation's most serious problems is the lack of uniform access to health and medical care for *all* members of the population. This problem is most prominent in inner city and rural areas.

The existing inequities in the health care system are often blamed on a national shortage of medical manpower and associated facilities [2]. The distribution of these limited resources intensifies this apparent shortage. For example, the doctor per person ratio is 1:518 in New York, 1:1,340 in Mississippi, and 1:1,448 in Arkansas [12]. Even wider differences exist within some state boundaries. In Virginia, the ratio is 1:558 in metropolitan areas and 1:2,243 in rural areas [10].

Several states are attempting to solve the problems of health care delivery by locating small satellite clinics in needy areas. The clinics are staffed by allied health personnel, who give primary treatment for minor routine care, meet emergency needs, offer health care advice, provide referral services for advanced treatments, and determine financial eligibility for assistance programs [1]. Transportation service is available at some clinics to bring patients to the clinic, and when necessary, take them to a central medical facility for access to more specialized and highly trained medical resources.

The location of such clinics is of utmost importance if they are to be successful and achieve the maximum benefit. A number of factors influence the use of medical facilities. One is the distance that an individual must travel to reach the clinics. This is directly related to accessibility. If we are concerned with improving the accessibility to medical resources for all members of population, then one objective which may be pursued when locating a given number of clinics is to select sites which minimize the total travel required of the population in securing health care.

This paper reports a procedure that can be used to select clinic sites which will minimize total travel requirements of patients. Analytical data requirements and results of an empirical analysis which determined the best locations for Health Outreach Clinics (HOC) are also presented.[1]

THE LOCATION MODEL

The computational procedure used is a concise and efficient heuristic algorithm developed by Shannon and Ignizio for use in warehouse location problems [11]. Other uses for the procedure are presented by Hardy [3, 4], as well as Ignizio [5]. The procedure is similar to that presented by Stollsteimer [13] and later extended by others, as the computational logic is based upon finding the combination of n possible locations taken m at a time which will minimize the values given in the cost matrix, where m is the number of locations to be

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[1] The Health Outreach Clinic concept proposes that small clinics be placed in needy areas with a nurse practitioner being the primary staff. Patients visiting the clinics who need services of more highly trained medical professionals are referred to a medical center for such services [9].

established.

The basic locational model used in the analysis may be stated in general form:

(Minimize total patient miles traveled, TPM.)

(1) $\text{Min TPM} = \text{Min} \sum_{ji}\sum ((C_{ijk}(X_{ijk}) + C_{ij}(X_{ij}))(z_{ij}Y_j))$ for all k.

Subject to the constraints

(Total service demand is satisfied at all demand centers, i.)

(2) $\sum_{kj}\sum(X_{ijk} + X_{ij}) = D_i$ for all i,

(Service capacity is not exceeded at each HOC, j.)

(3) $\sum_{ki}\sum(X_{ijk} + X_{ij}) \leqslant H_j$ for all j,

(Service capacity is not exceeded at each central facility, k.)

(4) $\sum_{ji}\sum(X_{ijk}) \leqslant C_k$ for all k,

(The number of HOCs, j, to be located is not exceeded.)

(5) $\sum_j Y_j \leqslant F$,

(The expected utilization at each demand center, i, is assigned to only one location.)

(6) $\sum_j z_{ij} \leqslant 1$ for all i,

where:

X_{ijk} is the number of patients moving from their home in demand center i, through HOC j, and on to the central facility k,

X_{ij} is the number of patients moving from their homes in i who have their medical care needs met at clinic j, and do not move further in the health care system,

C_{ijk} and C_{ij} are the "costs" or miles traveled associated with each particular movement. (A maximum limit may be set on the number of miles that can be traveled from the demand centers to the HOCs. Any cost above the specified limit is raised to a very large value to indicate infeasible travel.),

D_i is the medical service demand for each particular demand center i,

H_j is the service capacity at each HOC j,

C_k is the service capacity at the central facility k,

Y_j is 1 if a HOC is located at j,
is 0 if HOC is not located at j,

z_{ij} is 1 if demand at i is assigned to j,
is 0 if demand at i is not assigned to j, and

F is the number of HOCs to be located.

For simplification and clarification, the following specific assumptions were necessary:

1. Each HOC has the same initial basic construction cost. The future size and staffing may vary according to the expected demand, thus the service capacity constraint (3) is not active.
2. Each HOC operates independently of all other clinics, i.e., there is no referral from one clinic to another.
3. Existing medical facilities will continue to serve the same number of patients as in the past, with those patients coming from the same geographic area as in the past. Also, these facilities are assumed to have enough capacity to handle all referrals, thus service capacity constraint (4) is not active.
4. Utilization of HOC services will be based upon the expected need for comprehensive and preventive health care.
5. Expected occurrences of accident and emergency cases is not considered when determining the expected demand, because of their completely random nature.
6. The population of the area served by a HOC is aware of the availability of the services and travels to the clinic by the most direct route over all-weather roads to secure care.
7. All referrals for more complete or specialized treatment will be sent to a single medical center, thus k becomes 1.

DATA REQUIRED

The location model was used to determine the best locations for Health Outreach Clinics in a central Virginia planning district. The district covers 2,182 square miles, is basically rural and contains the independent City of Charlottesville. A total of 115,235 persons reside within the district. Figure 1 illustrates the spatial relationship of counties considered. Albemarle County was selected as the central county since its health department would have the responsibility of supervising the proposed clinics. Also, the City of Charlottesville, with the University of Virginia Medical Center, is located in this county and was specified as the central point to which all clinic referrals would be made.

The complete location analysis required primary data on all possible clinic locations, all possible health care demand centers, travel distances for that portion of the population seeking health care at clinics, and

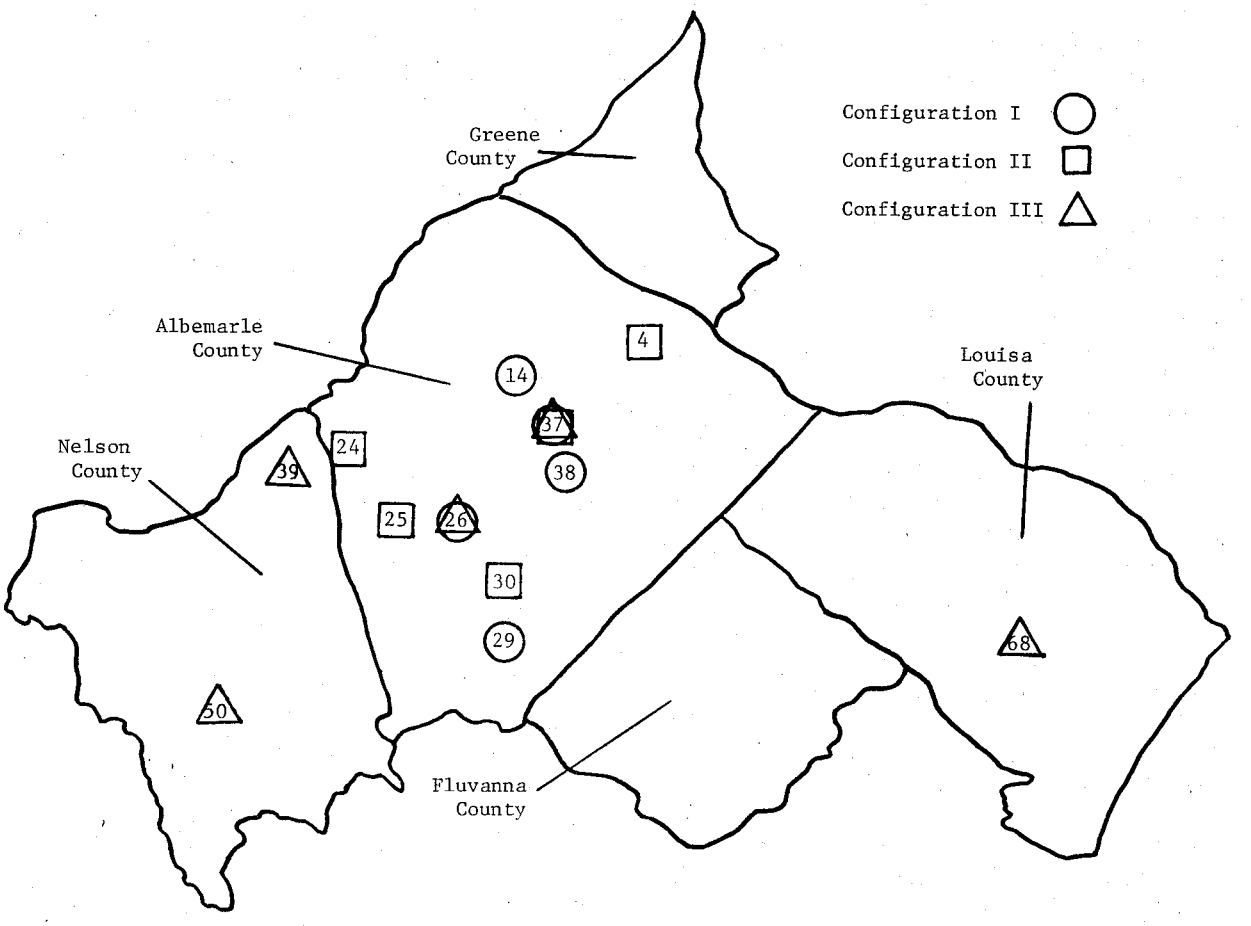

Figure 1.BEST FIVE LOCATIONS FOR RURAL HEALTH CLINICS WITH FIFTY PERCENT REFERRAL RATE AND NO TRAVEL DISTANCE RESTRICTIONS, SELECTED WITH SOLUTIONS SUBJECT TO THE THREE AREA CONSTRAINT CONFIGURATIONS.

potential elements for clinic services.

Selecting Possible Clinic Locations

All possible clinic locations are first specified. Each location specified was an intersection of all-weather roads close to the population-weighted center of a Census Enumeration District. The enumeration district represented a workable size unit for which population data could be obtained and boundaries easily identified. Also, the number of districts was small enough to give a manageable number of possible locations. Eighty-six locations were specified in the non-city area of the planning district, and the 57 enumeration districts in the City of Charlottesville were combined to give two possible locations. Thus, the five county area enclosed 88 possible Health Outreach Clinic locations, of which, 38 were in Albemarle County. Each location specified was labeled with a number – 1 through 88.

Selecting Demand Centers

Demand for clinic services comes from individuals who travel from their homes to the clinic to secure health and medical care. Considering each household as a single demand center would provide the most exact representation of demand within an area, but would be computationally impractical. A simplification was made. Each enumeration district was designated as having a single demand center located at the point previously chosen as a possible clinic site.

Determining Travel Distances

After possible locations and their associated demand centers were specified, county highway maps

were used to determine the minimum all-weather road distance from each demand center to every possible clinic location site. Since the possible clinic location site and the demand center in each enumeration district were assumed to be the same point, travel within each district was zero.[2]

Determining Potential Utilization

Several data sources were required to derive the expected utilization rate for the proposed clinics. Population data for each enumeration district were obtained from Census Computer Tapes. Annual physician visit rates were obtained by sex and race by age groups from data published by HEW [14]. These visit data are based on national averages and were justified for use in this analysis by McCormick and Miley in their study of a rural Virginia county [7].

Population data were multiplied by the physician visit rate data to obtain the expected physician visits for each of the 88 demand centers. Table 1 shows the data and results of the procedure used to determine expected demand for a single demand center.

The expected annual physician visit demands were adjusted to account for the existing medical force. Present physician annual case loads were estimated from a survey of the existing rural and urban general practitioners, the outpatient departments, and all clinics within the area. These estimated annual case loads were used to adjust expected annual physician visits and obtain a net demand or expected utilization for the proposed clinics.

Table 1. EXAMPLE OF CENSUS ENUMERATION DISTRICT POPULATION DATA AND THE EXPECTED NUMBER OF ANNUAL PHYSICIAN VISITS PER PERSON BY RACE, SEX, AND AGE, WITH TOTAL EXPECTED VISITS

	White				Non-white				
	Male		Female		Male		Female		Total
Age	Population	Expected visits	Population	Expected visits	Population	Expected visits	Population	Expected visits	expected visits
	Numbers								
Under 5 years	24	6.4	30	6.0	9	3.8	12	2.9	402.6
5 - 14 years	108	3.0	89	2.9	28	1.3	36	1.3	665.3
15 - 24 years	76	3.3	58	5.0	12	1.9	17	3.6	624.8
25 - 34 years	58	2.8	56	5.9	6	3.9	12	5.0	576.2
35 - 44 years	54	3.6	50	5.0	12	2.7	11	5.1	532.9
45 - 54 years	41	3.8	52	4.9	7	3.6	17	4.4	510.6
55 - 64 years	40	5.0	49	5.4	7	3.8	9	3.7	524.5
65+ years	39	5.5	37	6.5	9	4.3	9	5.6	544.1
Totals	440	...	421	...	90	...	123	...	4381.0

After all adjustments in the data were completed, it was determined that 301,278 annual clinic visits could be expected from residents of the entire area. Of this total, 222,382 were located in Albemarle County and Charlottesville.

Designating a Referral Pattern

The Health Outreach Clinic concept assumes that patients who need additional or more specialized treatment than that available at such a clinic will be referred to a better equipped, central facility having a more highly trained staff. The number of persons requiring referral is an important factor in determining proper locations for all clinics. Theoretically, one would expect that, in minimizing total travel distance, clinics should be located closer to the central facility as the rate of referral is increased. Site 37, located in the City of Charlottesville, was specified as the central facility to receive all referrals.

Estimates vary as to the percentage of the expected case load that could be handled at a clinic. McCormick and Miller indicated that allied health care personnel could care for 37 percent of all

[2] This provides a close approximation to actual distances traveled since some residents of an enumeration district will travel less and some more to a clinic located outside their own district. This will understate the distance traveled by residents to clinics located within their own district.

pediatric cases and 12 percent of all cases involving adults could be handled without a physician [8]. Lave, Lave and Morton found that a paramedic could satisfactorily care for from 30 to 81 percent of all cases encountered [6]. Unfortunately, this wide range of estimates made it difficult to establish a very precise estimate for the number of referrals required.

EMPIRICAL RESULTS

In addition to determining the best locations for clinics, the location analysis revealed those variables which have a significant effect on the location decision, thus indicating where special care should be used in data preparation and analysis. Three variables appear relevant in this aspect: (1) the demand area and possible locations being considered, (2) the percentage of total demand referred from each clinic to the central facility, and (3) the feasible distance that clinic patients would travel from their respective demand center to a possible location.

Demand Area Constraints

Obviously, the possible locations considered and the demand area served would have a significant effect on the locations selected as best. Figure 1 and Table 2 give the best locations and associated information for three different possible location and demand area configurations. For each solution, it was assumed that patients were not restricted in the distance that they could travel from their particular demand center to a possible site, and that there was a 50 percent referral rate.

Since the health department serving Albemarle County and Charlottesville is expected to have primary control over the proposed clinics, one best location pattern was derived which considered only the possible locations and demand centers within that area, Configuration I in Table 2. The numbers enclosed with circles in Figure 1 identify these locations.

The results obtained when the expected demand for the entire five-county area was recognized, but again, only locations in Albemarle County were considered possible are presented as Configuration II in Table 2. The numbers enclosed by squares in Figure 1 identify these locations.

Configuration III in Table 2 gives the results when all possible locations and demand centers in the five county region were considered. The locations selected are enclosed by triangles in Figure 1.

Comparison of these three sets of results indicates the importance of correctly specifying the location and service area. Comparing Configurations

Table 2. BEST FIVE LOCATIONS FOR RURAL HEALTH CLINICS USING THREE AREA CONSTRAINT CONFIGURATIONS WITH FIFTY PERCENT REFERRAL RATE AND NO TRAVEL DISTANCE RESTRICTION

--Configuration I-- Only Albemarle County* possible locations and demand centers			--Configuration II-- Only Albemarle County* possible locations but all demand centers			--Configuration III-- All possible locations and demand centers		
Site number	Clinic visits	Average miles	Site numbers	Clinic visits	Average miles	Site number	Clinic visits	Average miles
37	137,801	1.81	37	221,897	5.41	37	226,725	4.22
26	13,785	10.69	25	22,334	23.55	50	19,850	25.05
38	57,403	2.60	30	20,140	16.78	68	15,291	24.10
29	5,105	9.11	4	19,154	11.70	26	28,022	14.64
14	8,288	4.85	24	17,753	20.60	39	11,390	13.54
Totals	22,382	2.85		301,278	8.81		301,278	7.92

*Includes city of Charlottesville

II and III shows the gains that can be realized from regional cooperation. If Albemarle County alone attempted to serve the region's needs, each patient visit would require an average of 8.81 miles travel. From a planning district viewpoint, Configuration III, the total demand could be served at an average of 7.92 travel miles per visit. Configuration III would save, on an annual basis, more than 250,000 patient miles when compared to Configuration II. At 12 cents per mile, an annual saving of $30,000 in travel costs could be realized.

Note that in all three solution sets, location 37 was selected as one of the five best locations. This fact emphasizes the importance of the central medical

Table 3. BEST FIVE LOCATIONS FOR RURAL HEALTH CLINICS WITH VARIED PATIENT REFERRAL RATES AND NO TRAVEL RESTRICTIONS – ALL POSSIBLE LOCATIONS AND DEMAND CENTERS CONSIDERED

--Situation A-- Twenty-five percent referral rate			--Situation B-- Fifty percent referral rate			--Situation C-- Seventy-five percent referral rate		
Site number	Clinic visits	Average miles	Site number	Clinic visits	Average miles	Site number	Clinic visits	Average miles
37	223,303	3.91	37	226,725	4.22	37	238,251	4.92
68	17,492	16.83	50	19,850	25.05	48	16,004	31.28
50	22,027	16.29	68	15,291	24.10	74	15,072	30.52
30	24,503	10.96	26	28,022	14.64	40	13,434	26.14
39	13,953	9.86	39	11,390	13.54	26	18,517	15.40
Totals	301,278	6.41		301,278	7.92		301,278	9.19

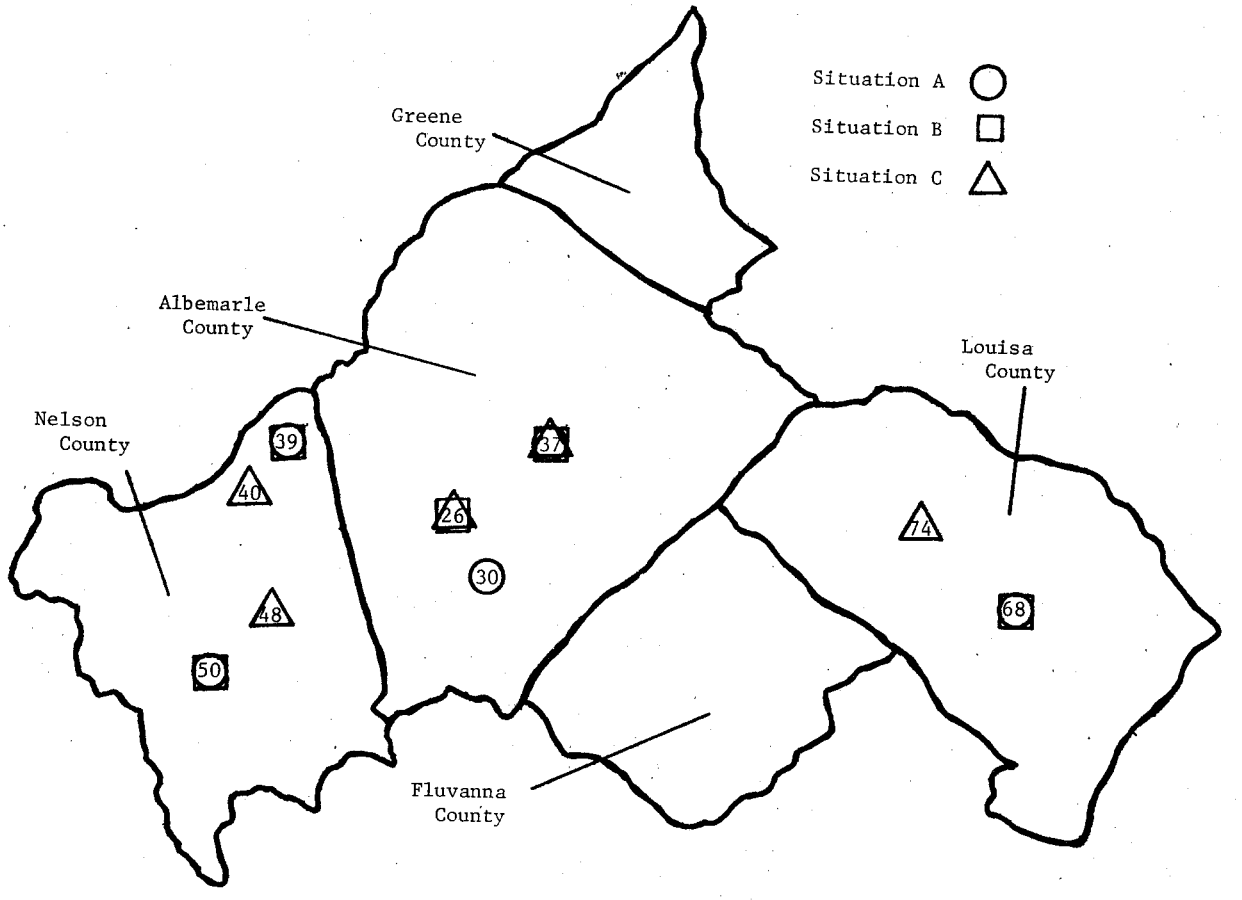

Figure 2.BEST FIVE LOCATIONS FOR RURAL HEALTH CLINICS WITH VARIED REFERRAL RATES AND NO TRAVEL RESTRICTION – ALL POSSIBLE LOCATIONS AND DEMAND CENTERS CONSIDERED.

facility in serving the total health care needs of the study area.

Patient Referral Constraints

Table 3 and Figure 2 present the variations in the best locations selected when the referral rate was set at different levels. The referral rate was 25 percent for Situation A, 50 percent for Situation B, and 75 percent for Situation C. In each case, travel distance was not restricted and all possible locations and

Table 4. BEST FIVE LOCATIONS FOR RURAL HEALTH CLINICS WITH FIFTY PERCENT REFERRAL AND VARIED TRAVEL RESTRICTIONS -- ALL POSSIBLE LOCATIONS AND DEMAND CENTERS CONSIDERED

--Situation D-- Five mile travel restriction				--Situation E-- Ten mile travel restriction				--Situation F-- Fifteen mile travel restriction			
Site number	Clinic visits	Average miles	Percent served	Site number	Clinic visits	Average miles	Percent served	Site number	Clinic visits	Average miles	Percent served
9	168,847	2.23	56	37	191,833	1.87	64	9	207,830	3.75	69
50	8,608	21.06	3	40	15,790	17.10	5	45	26,225	20.39	9
26	6,918	8.06	2	87	16,232	15.52	5	72	17,295	24.55	6
33	6,756	8.10	2	31	15,495	15.23	5	88	18,334	14.85	6
24	6,541	10.81	2	50	14,183	22.63	5	50	19,850	25.05	7
Totals	197,670	3.74	65		253,533	5.67	84		289,634	7.20	97

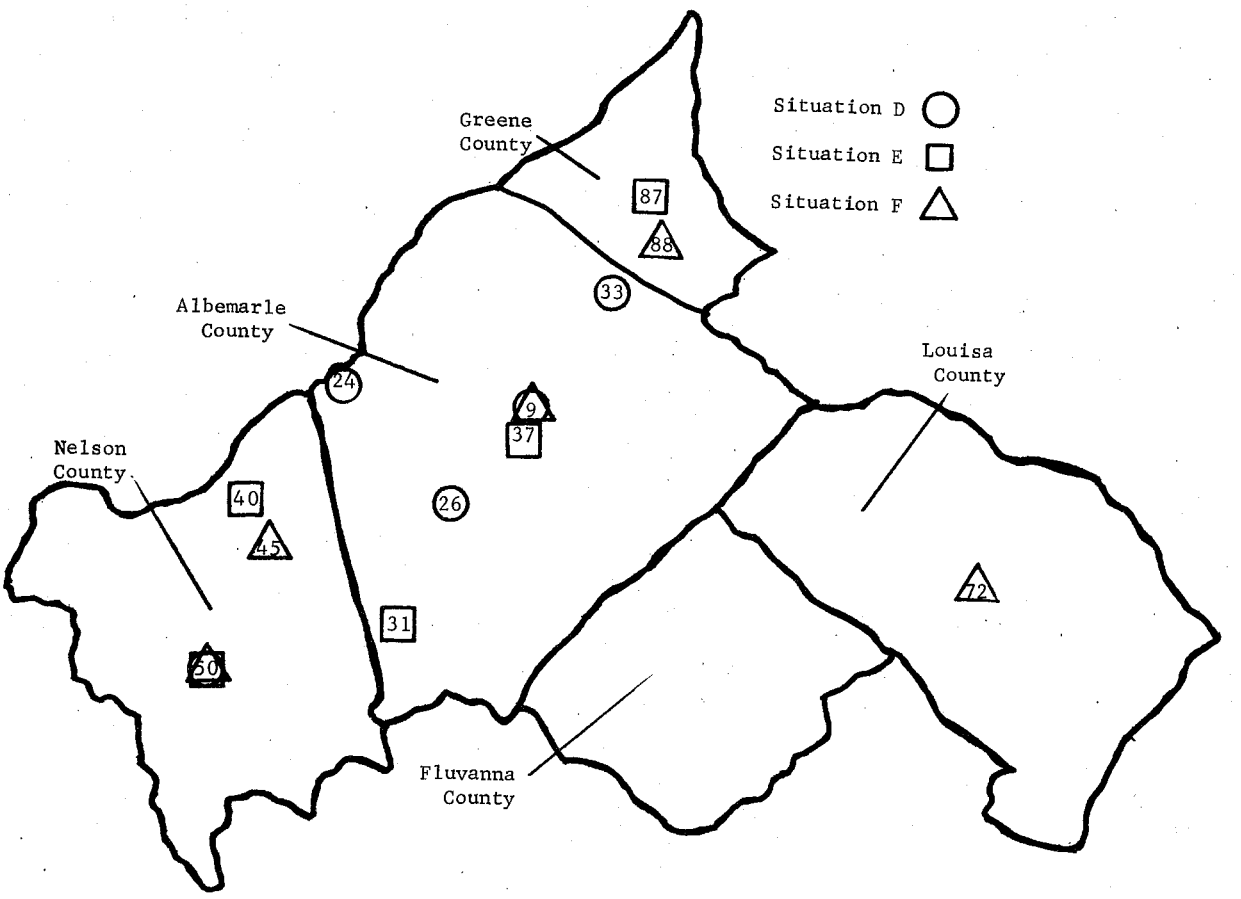

Figure 3.BEST FIVE LOCATIONS FOR RURAL HEALTH CLINICS WITH FIFTY PERCENT REFERRAL AND VARIED TRAVEL RESTRICTIONS -- ALL POSSIBLE LOCATIONS AND DEMAND CENTERS CONSIDERED.

demand centers were considered, i.e., Configuration III. Locations selected as the best five varied among the three situations, and average total travel required to serve the entire population increased as the rate of referral increased. This would be expected. Also, locations selected as best tended to move somewhat closer to the specified central referral point as the referral rate increased. Again the only location

selected by all three solution groups was number 37.

Travel Distance Constraints

Table 4 and Figure 3 illustrate how the locations selected varied as the distance that patients could travel one-way from their demand center to possible locations was restricted. This analysis was necessary because there is some question as to how far patients will be willing to travel to utilize the services of the clinics. Situation D gives the best locations when persons were not allowed to travel over five miles from their particular demand center to a possible location. Situation E set the travel maximum to ten miles, and Situation F assumed a fifteen mile limit. In each solution Configuration III constraints and a 50 percent referral rate were assumed.

Comparison of the three solution sets in Table 4 indicates a high degree of variability among the locations selected as best. As permissible travel distances increased, the percentage of the population served increased, and the locations selected moved farther away from the central facility. When a five mile travel restriction from demand center to possible location was imposed, four of the five locations selected were in Albemarle County. Also, only 65 percent of the expected annual visits within the planning district could be served with five clinics. When it was assumed that patients would be willing to travel fifteen miles for treatment, 97 percent of the expected annual visits could be served with five clinics.

Table 5. BEST LOCATIONS FOR RURAL HEALTH CLINICS FOR VARIOUS NUMBERS OF CLINICS, WITH ALL POSSIBLE LOCATIONS AND DEMAND CENTERS CONSIDERED, FIFTY PERCENT REFERRAL RATE, AND TEN MILE ONE-WAY TRAVEL RESTRICTION

Number of clinics	Location numbers	Cumulative total of		Population served per additional clinic	Percent of population served
		Patient visits	Miles traveled[1]		
1	37	191,833	358,374	46,788	64
2	37, 40	207,623	628,447	3,850	69
3	37, 40, 87	223,855	840,431	3,959	74
4	37, 40, 87, 31	239,350	1,116,435	3,839	79
5	37, 40, 87, 31, 50	253,533	1,437,375	3,400	84
6	37, 40, 87, 31, 50, 72	265,412	1,694,115	2,897	88
7	37, 40, 87, 31, 50, 72, 78	273,987	1,836,754	2,092	91
8	37, 40, 87, 31, 50, 72, 78, 60	279,825	1,926,974	1,424	93
9	37, 40, 87, 31, 50, 72, 78, 60, 65	283,237	2,014,375	832	94
10	37, 40, 87, 31, 50, 72, 78, 60, 65, 52	286,173	2,085,800	716	95

[1] Travel for only those patients living within ten miles of a clinic. These results assume that no one will travel more than ten miles to a clinic.

Determining the Number of Clinics

The results presented so far have emphasized the importance of several constraints and how they affect selection of the best locations for Health Outreach Clinics. A decision maker charged with planning for rural health services is also concerned with information which would aid in establishing the proper number of clinics. Data presented in Table 5 for the set or sets of constraints selected as being realistic would aid in this decision. Table 5 gives relevant information for locating from one to ten clinics, selected with all locations and demand centers being considered, a 50 percent referral rate, and a ten mile one-way travel restriction.

The data indicate, for example, that the best three locations are sites 37, 40, and 87. Locations 37, 40, and 87 have 74 percent of the district's expected service population living within ten miles and could expect to serve 223,855 patient visits annually. These patients will travel a total of 840,431 miles in securing care. The addition of the third clinic at location 87 permits 3,959 more people to have medical services within ten miles of their home.

This last bit of information -- the number of persons gaining greater access to health services -- is important from a social welfare point of view and is of prime interest in selecting the best number of clinics. If the decision maker has some idea of the public or social cost involved when an individual does not have ready access to health services, he can then determine if the annual costs associated with establishing and operating an additional clinic can be justified.

Little data is available concerning the social or public cost incurred if a person does not have adequate access to medical care. This is an important problem and a fertile area for extensive additional research.

SUMMARY

This paper has presented a procedure and its associated data needs for determining the best locations for rural health clinics. It is assumed that the clinics will be staffed by allied health personnel and will, of necessity, have to refer some patients to a central facility for treatment by more highly trained medical practitioners.

The results of an actual analysis utilizing the procedure presented demonstrated that site selection is very sensitive and is affected by several variables. The geographic configuration of the area being considered, the percentage of the patients referred to a central medical facility, and the distance considered as feasible for travel all have a significant effect upon the location selection process.

A final problem facing the health planner is the decision of the best number of clinics to establish. The social cost incurred if persons do not have adequate access to health services must be developed and compared to the annual clinic cost to determine the proper number of clinics. Determining the estimates of the social cost would justify additional research.

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