ON DEPLOYMENT OF HEALTH RESOURCES IN RURAL VALLE DEL CAUCA, COLOMBIA

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Special Project Report

ON DEPLOYMENT OF HEALTH RESOURCES IN RURAL VALLE DEL CAUCA, COLOMBIA

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ON DEPLOYMENT OF HEALTH RESOURCES IN RURAL VALLE DEL CAUCA, COLOMBIA[1]

ABSTRACT

Local planners in Zarzal, Valle del Cauca, used census data and common sense to determine good centers from which to recruit rural health workers and at which to base ambulances. Their task can be formulated as a maximal covering location problem and was solved with both a heuristic appropriate to the local computer system and integer programming. Location analysis found better centers for health workers than did the local planners, in the terms of reference of the planners themselves. The ambulance deployment study suggested advantages to modifying system management practices. A portion of the specific recommendations have been implemented in Zarzal. The covering techniques are being applied by planners in other areas of Colombia.

INTRODUCTION

This paper reports on the data collection, problem formulation, analysis, and conclusions of a joint Colombian-American Study to integrate the use of location analysis into rural health planning in Colombia.[2] The site for this pilot

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study was Zarzal, a five county region in the state of Valle del Cauca, Colombia. A special sanitary survey was conducted to gather information on rural areas with insufficient access to the health system. Village population and altitude, travel times and distances between villages, and the status of existing health, water, and electricity services were ascertained by village visits. Based on this information and the common sense application of Colombian Health Ministry planning norms, several Valle planners selected some villages to be health centers at which to recruit rural health outreach workers and other sites to be bases for medical vehicles.

When formulated in optimization terms, both rural health center and ambulance extension problems were found to be variants of the maximal covering location problem. Since an integer programming code was not available a heuristic was utilized that yielded good solutions that could be tested for optimality by linear programming. The investigators then used maximal covering to assess the potential for improving the deployment of rural health centers and the medical vehicle system.

BACKGROUND

Numerous authors over the past decade have considered the topic of optimum location of facilities to provide health services. Savas [36], Bell and Allen [4], Morrill and Earickson

[27], Smith [42], Schultz [38], Stidham [44], Stidham, et. al. [45], Stevenson [43], Volz [50], Chaiken and Larson [10], Calvo and Marks [8], Fitzsimmons [17], Berlin and Liebman [5], Dear [13], Shannon and Dever [41], Cretin, [12], Landau [22], Willemain [51], Larson [23,24], Berlin et.al. [6], Öberg [30], and Kropp [21], have each made contributions to the literature. Many of these papers have been reviewed by ReVelle, et.al. [34], Chaiken [9], and Savas [37].

Several of the algorithms that can be used to site health facilities have been made available to operating agencies for possible use. Chaiken reports, for example, that Larson's hypercube queuing model [23,24] and Toregas and ReVelle's set covering model [46,47], have been acquired by 39 and 54 recipients, respectively [9].

There have also been several applications of systems techniques to the health facility location problems of Third World nations, including the efforts of Sen, et.al. [39], Fisher, et.al. [16], Banerji and Fisher [1], Harvey, et.al. [20], Narula, et.al. [29], Rushton and Fisher [35], Eaton et.al.[15], and Narula and Ogbu [28]. These health facility location approaches and the EMS literature have apparently not been widely transferred to operating agencies in Third World countries. This paper reports on the results of one effort to develop and use an appropriate health facility siting methodology and transfer it to several health agencies in Colombia.

THE PUESTO SITING PROBLEM

Rural areas in Colombia, as in other Third World countries, are characterized by both high mortality rates due to preventable diseases and inadequate access to health services. For example, three of the top four causes of death in Colombia are preventable diseases - gastroenteritis, non-viral pneumonia, and bronchitis [25]. Together these three diseases account for more than half the infant mortality in Colombia, which in 1975 was 67 deaths per thousand infants[3] [2]. While about 10,000 physicians practice in Bogotá, the capital, a total of only 372 doctors practice in all the local hospitals throughout Colombia [48].

In response to this situation of high disease incidence and low access to medical care, the Ministry developed a program of extension of health care to rural areas through health promoters called "promotoras." A typical promotora is a woman between the ages of 18 and 35, who is recruited from a specific village to receive training and then returns as a health promoter. Her role is to serve as the primary contact person for preventive health; her tasks,

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3 For purposes of comparison, the 1975 mortality rate in the United States was 16.1 deaths per thousand infants [14,pp. 7-72].

as described in table 1, include health education, provision of basic medical attention, and promotion of personal hygiene. A promotora will either operate out of her home or a rural health outpost, if there is one in the village. The promotora is trained and supervised by nurses, dentists, and doctors who are located in local or regional hospitals [31,32]. Patients with health problems requiring treatment beyond first aid are referred to a hospital. Hospitals are organized in a hierarchical fashion, ranging from a local hospital that can treat minor problems, to regional and university hospitals that offer a full range of medical services.

TABLE 1

THE BASIC SERVICES OF THE PROMOTORA

Education	*Personal Hygiene*	*Medical Attention*
Family Planning	Teaching personal hygiene	First Aid
Nutrition	Teaching people to boil water	Providing basic medicines
Prenatal instruction and care	Assisting in the installation of latrines and toilets	Giving vaccinations
Postnatal instruction and care	Promoting adequate disposal of garbage and human wastes	Aid to malnourished children
Advice on growth and development of children		Referral of patients to the local hospital

Although 18,000 promotoras were needed to provide adequate contact with the rural population, the Ministry estimated that only 3,000 were operating in 1974. [48]. In 1975, the Ministry of Health made a commitment to employ more rural promotoras.

To efficiently plan for extension of the rural health promotora system, Ministry officials faced a two-staged problem: (a) which village should have a puesto and (b) how many promotoras are needed, based upon some operational definition of promotora work load. To estimate the number of required promotoras in a puesto, the Ministry developed a complicated "promotora-hour formula" that added up service requirements for home and school visits as well as open clinic hours, and decided by the available hours for work. To simplify calculations, the Ministry estimated that a promotora should serve no more than 200 families, or about 1000 persons [48].

The Ministry was unable to develop a satisfactory procedure for selecting and assigning responsibilities to those villages, called puestos de salud (health centers), that serve as promotora bases. Health planners [4] in Valle del Cauca, one of the Colombian states, decided to develop their own procedure for determining

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4 The expression "Valle planners" refers, among others, to Luis Guillermo Valencia Lopez and Rodrigo Bustamante Alvarez, both co-authors of this paper and employees of the Health Services of Valle del Cauca.

health center sites based upon measurable criteria reflecting community infrastructure and human limitations. They decided that a town with an existing hospital should be ineligible as a puesto site because the priority of the system is to cover rural areas. Any village that would be effectively served by existing promotora(s) should also be ineligible as a site, since new promotoras would only duplicate existing services. The Valle planners reasoned that promotoras should be recruited from those villages most accessible to the rural clientele. Their measure of accessibility was the number of persons who could reach (or be reached by) a promotora from a health center. Initially promotoras served only their own villages. For the purpose of this study, the Valle planners allowed travel between villages, subject to an upper limit on human exertion. The Valle planners set 7.5 kilometers (or one hour one way, whichever was shorter) as the upper limit for promotora walking between villages. They also decided that a promotora should not serve a village if to do so would require her either to ascend more than 100 meters above the health center or descend in excess of 30 meters. One rationale for the 30 meter descent limit was that an ill person should not have to ascend more than 30 meters higher than his own village to visit the promotora. Also, the ill persons traditionally go down (not up) looking for help [7].

The Valle planners also reasoned that electricity and "acceptable water" should be prerequisites of a good health center site. Electricity is desirable because it would allow the promotora to store vaccines in an electric refrigerator. Kerosine refrigerators were rejected as an option for keeping vaccines due to difficulties in maintaining the puestos' kerosine supply. Acceptable water was defined by the Valle planners as any village where 80 or more percent of the village population obtained water from an uncontaminated source. Acceptable water would be a valuable convenience for operating a puesto.

The seven factors to be used in selecting villages for puesto location are listed in table 2. Use of these factors in planning was difficult due to problems of obtaining accurate information. Data on village water supply are incomplete at the state or national level. No measurements of time of travel between villages were available, and maps were considered to be out of scale. Estimates of village population kept at the national level were incomplete (some towns were not counted by the Colombian census bureau), and when available were considered to undercount the rural residents [2].

TABLE 2

FACTORS IN HEALTH CENTER SITING IN ZARZAL

1. Promotoras should not have to travel more than 7.5 kilometers or more than one hour (whichever is less) one way between a health center and a client village
2. Promotoras should not have to ascend more than 100 meters or descend more than 30 meters in travel between a health center and a client village
3. A health center should not be sited in towns with hospitals
4. A health center should have electricity service
5. A health center should have a potable water supply
6. A health center should not be established in a village which already has an existing health center
7. A health center should be sited in a village that is as accessible as possible to the unserved rural population

As the basis for an extension of the rural health system, the Valle planners designed and conducted a field sanitary survey. This survey, which involved approximately 276 person-months of work during June 1976 to May 1977, collected observations of village population, housing and schools, sanitary practices, location and status of existing health facilities, etc., as listed in table 3 [49].

TABLE 3

PARTIAL LIST OF DATA COLLECTED IN VALLE SANITARY SURVEY

Population

Number of persons, by age group

Number of persons, by sex

Number of persons, in school

Leadership

Identification of community leaders

Identification of channels for health problems

Geography

Community altitude

Road network

Distance and time of travel to all neighboring villages

Homes

Number and location of existing homes

Hygienic conditions of homes

Presence of animals in homes

Food handling and storage in homes

Schools

Number of schools

Existence of water supply and waste disposal system

General sanitary conditions

Presence of animals in schools

Existence of homes within schools

Utilities

Existence, origin, and sufficiency of water supply

Existence and performance of waste disposal system

Detailed information on design and location of (a) aquaducts; (b) wells; (c) sewage systems; (d) solid waste disposal

Existence and reliability of electricity supply

Health Institutions

Existence of promotora, midwives, or other health workers

Existence of health outpost

Design and condition of outpost

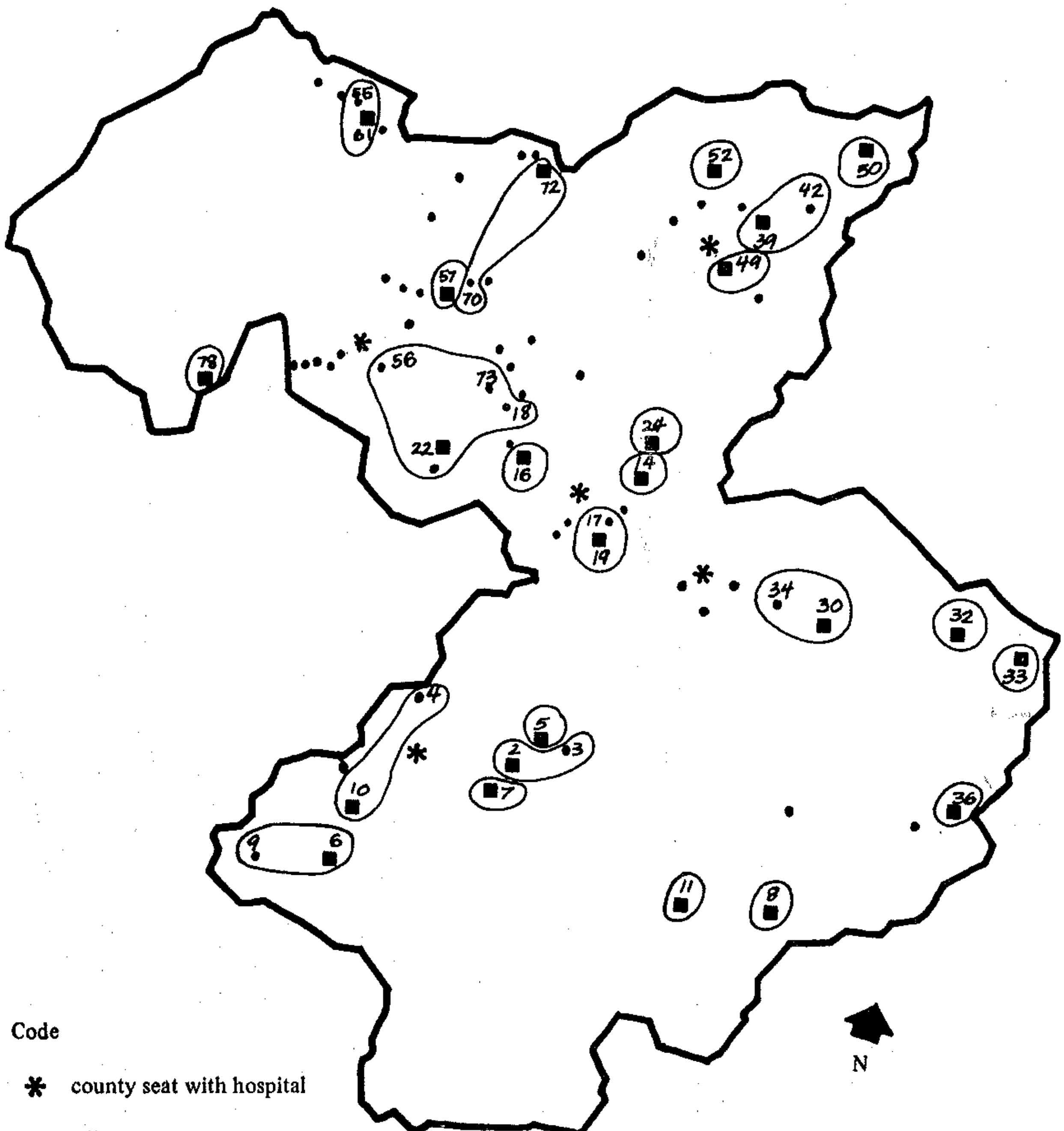
Based on this detailed survey data, and the seven factors of table 2, the Valle planners used common sense to determine 24 health centers from which to recruit promotoras in a pilot-study region called Zarzal. This five county area is approximately 1,281 square kilometers, or two-fifths the size of the state of Rhode Island. The rural population of 25,007 live in 74 villages and towns that are built along a river valley and up the side of the Andes (see figure 1). This area is enlarged in figure 2, where the sites of promotoras and hospitals are indicated by squares and stars, respectively. Table 4 is a listing of the population, altitude, water supply, and electricity data collected for the Zarzal villages [2,40].

Without exceeding the limits on travel time or altitude change, and with one promotora based at each of the 24 Zarzal health centers, 35 villages are covered (as shown by the enclosing shapes in figure 2). The villages selected as health center sites do not always comply with the Valle planners' own standards. Fifteen of the twenty-four health centers are in villages with electricity and only eight sites have acceptable water. Three promotoras serve alone in villages with populations in excess of 1000 persons [3]. If each promotora were to serve just 1000 persons, the 24 promotoras could reach 57 percent of rural Zarzal's population. Counting total village residents, promotoras and health centers are accessible to 78 percent of the population.

The Valle planners' method of health center site selection has several disadvantages that preclude its use in other areas of Colombia. The siting decisions are based upon sanitary survey information that may not be available in areas outside of Valle del Cauca. Although a group of health workers devised a simplified survey method that would be easier to apply to all of Colombia [26], any field survey is likely to be relatively expensive, time consuming, and labor intensive.

FIGURE 1: THE ZARZAL REGION

FIGURE 2
VILLAGES SERVED BY PROMOTORAS IN ZARZAL'S HEALTH CENTERS



Code

✱ county seat with hospital

● village

■ health center (village with promotora)

Numbers indicate village reference numbers.
Enclosing shapes indicate geographical service areas.

TABLE 4

INFORMATION FROM THE ZARZAL CENSUS–POPULATION, ALTITUDE, ELECTRICITY, WATER

No.	*Village*	*Population by Census*	*Altitude (meters)*	*Electricity*	*Acceptable Water*	*No.*	*Village*	*Population by Census*	*Altitude (meters)*	*Electricity*	*Acceptable Water*
1	Zarzal (county seat)		950			41	El Cedro	144	1645	Yes	
2	Alizal	148	1012			42	Guachal	35	938		
3	Chaquiral	60	998			43	La Cayetana	43	930	Yes	
4	El Vergel	64	930			44	La Chica	106	1252		
5	Guasimal	115	1000			45	La Quiebra	99	1430		
6	La Paila	5208	910	Yes	Yes	46	La Robleda	101	1660		
7	Limones	362	982	Yes		47	Patio Bonito	300	1740		
8	Quebradanueva	700	1050	Yes	Yes	48	Sabanazo	173	1510		
9	Rio Paila	736	910	Yes	Yes	49	San Antonio	578	970	Yes	Yes
10	Uña de Gato	80	935			50	San Francisco	1739	960	Yes	Yes
11	Vallejuelo	1306	1000	Yes	Yes	51	San José de Los Osos	94	1112		
12	Zambrano	72	932			52	Ventaquemada	267	1640		
13	La Unión (county seat)		930			53	Versalles (county seat)		1850		
14	Corcega	409	942	Yes		54	Altagracia	122	1860		Yes
15	El Guasimo	71	960	Yes		55	Arenillo	183	1540		
16	El Rincón	146	1460			56	Batambal	106	1728		
17	La Isla	126	919			57	Campoalegre	246	1760	Yes	
18	Las Violetas	77	1682	Yes		58	Coconuco	180	1663	Yes	
19	Linderos	263	919			59	Dos Quebradas	75	1850		
20	Lucero	343	960			60	El Arbolito	218	1380		Yes
21	Paramillo	155	1560			61	El Balsal	645	1529	Yes	Yes
22	Quebradagrande	387	1628	Yes	Yes	62	El Bosque	141	1720		
23	Sabanazo	413	1400	Yes	Yes	63	El Cedral	130	2052		
24	San Luis	989	950	Yes		64	El Cedro	46	1075	Yes	
25	San Rafael	83	919			65	El Diamante	193	1850	Yes	
26	La Victoria (county seat)		950			66	El Embal	160	1842		
27	Davila	106	1105			67	El Rubi	93	1480		Yes
28	El Guayabo	172	942	Yes		68	El Silencio	138	1550		
29	Guacará	192	945			69	El Tambo	148	1850	Yes	
30	Holguin	1310	985	Yes		70	Jigual	156	1720		
31	La Holanda	174	1254			71	La Arabia	64	1500		Yes
32	Miraralle	955	1415	Yes		72	La Florida	290	1720		Yes
33	Riveralta	471	1258	Yes		73	La Sonora	69	1700		
34	San José	376	960	Yes		74	Manzano	13	1850		
35	San Pedro	448	1000	Yes		75	Monte Azul	unknown	unknown		
36	Taguales	186	1292			76	Morroñato	109	1580		
37	Toro (county seat)		960			77	Murrapal	100	1620		Yes
38	Chonataduro	103	1570			78	Penoñes	346	965		
39	El Bohio	370	955	Yes	Yes	79	Puente Tierra	138	1700		Yes
40	El Bosque	43	1240								

Also, the method cannot be separated from the personalities of the planners. The planners must make a commitment to become intimately acquainted with each small planning area. Since the final siting decisions may involve breaking the planners' own rules, it is not easy to explain the decision process. These limitations led the authors to develop a procedure for planning rural health system extensions that could be more widely applied in Colombia.

Formulation of the Puesto Deployment Problem

The first step was to recognize that the Valle planners had already implicitly formulated their problem in mathematical programming terms. The principal decision variables are (a) whether or not to select a village to be a health center,

$$x_j = \begin{cases} 1 & \text{if village } j \text{ is selected as a health center} \\ 0 & \text{otherwise} \end{cases} \qquad j = 1,2,\ldots,n \qquad (1)$$

where n is the number of villages that are potential puestos de salud and (b) whether a village is accessible to a health center or not.

$$y_i = \begin{cases} 1 & \text{if a village is accessible to a health center} \\ 0 & \text{otherwise} \end{cases} \qquad i = 1,2,\ldots,m \qquad (2)$$

where m is the number of villages that are currently without access to health services. In some cases, n could equal m; that would occur if any village could serve as a potential site for a health center. M need not equal n. For example, if the number of potential health center sites were to be restricted for some reason, then n could be less than m. A village has access to promotora service if and only if there exists a health center at a site which can serve that village. For village i:

$$\sum_{j \varepsilon N_i} x_j \geq y_i$$

where N_i is the set of sites that could potentially serve village i. This set of potential health center sites consists of all villages that meet the five criteria or norms: (a) availablity of electricity; (b) availability of acceptable water; (c) no existing hospital; (d) altitude change between the site and village i that is within an upper and lower limit; and (e) travel time or distance between the potential site and village i does not exceed an upper bound. The subset of sites that meet the distance restrictions is

$$D_i = \{j | d_{ji} \leq s\} \qquad i = 1,2,...,m \quad (4)$$

where D_i is the subset of sites that involve travel that does not exceed the Service's limits, d_{ji} is the shortest distance between site j and village i, and s is the limit on distance or time of travel for a promotora, as set by the Service. The subset of potential sites that do not exceed the altitude change norms can be defined as

$$A_i = \{j \mid -30 \leq e_{ji} \leq 100\} \qquad i = 1,2,\ldots,m \qquad (5)$$

where A_i is the set of potential sites that comply with Service restrictions of promotora ascent and descent and e_{ji} is the altitude change (in meters) between any potential site j and village i. The subsets that meet the "no hospital", "acceptable water", and "acceptable electricity" standards are defined as

$$R = \{j \mid j \text{ has no hospital}\} \qquad i = 1,2,\ldots,m \qquad (6)$$

$$W = \{j \mid j \text{ has acceptable water}\} \qquad i = 1,2,\ldots,m \qquad (7)$$

$$E = \{j \mid j \text{ has electricity}\} \qquad i = 1,2,\ldots,m \qquad (8)$$

where R, W, and E stand for the subsets of potential sites that meet Service restrictions on existing hospitals, acceptable water, and electricity, respectively.

The set N_i can now be stated as:

$$N_i = \{D_i \cap A_i \cap R \cap W \cap E\} \qquad i = 1,2,\ldots m \qquad (9)$$

It would be straightforward to extend such an approach to other factors.[5]

The goal of the rural health extension program is to select puesto sites that are as accessible as possible to the rural clients. This can be defined as an objective of maximizing access to the rural population needing coverage in Zarzal:

$$\text{Maximize } Z = \sum_{i=1}^{m} a_i \, y_i \tag{10}$$

where a_i is the population needing coverage in village i. It is unlikely, given scarce resources for health, that the Ministry or Service could reach all the rural population. Thus the goal of maximizing access will be limited by the number of puestos that can be supported by the regional health budget,

$$\sum_{j=1}^{n} x_j = p \tag{11}$$

where p is the number of health center sites.

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5 For example, it is possible to include political party compatibility between the health center and any village it may serve. Most villages in Zarzal are dominated either by the Liberal or the Conservative party. The subset of potential health centers that are politically compatible with the party affiliation of a puesto site is:
$V_i = \{j \mid j$ has the same dominant party as $i\}$, $i = 1,2,\ldots m$.

There is another way of interpreting p that makes more sense in a multiobjective analysis. Planners do not always know a priori what the budget constraint will be and, indeed, sometimes help to determine it. By allowing p to vary over the full range of feasibility, the analyst can generate the tradeoff curve between the goals of "maximizing the coverage of the population currently without access" and "minimizing the number of health centers." The number of promotoras that the Service would need to deploy in these puestos could then be calculated by following the Ministry standard of one promotora per thousand clients. The formulation of the puesto selection problem is summarized in table 5; it is a variant of the Maximal Covering Location Problem (MCLP) defined by Church and ReVelle [11].

A Solution Technique

A second step was to develop procedures to solve this MCLP problem. The objective function and the constraint set consist of linear functions, with zero-one integer variables x_j and y_i; hence this problem has an optimal solution that can be found through integer programming. Neither the Ministry in Bogotá nor the Valle Health Service in Cali have access to an integer programming code. Although commericial and university-based linear programming codes exist in Colombia, it would be expensive for the Ministry to use them.

However, both the Ministry and the Health Service have their own computers whose use involves only paper transfers from one Ministry or Health Service account to another. Therefore we decided to develop a heuristic that would generate good and often optimal integer solutions, which could be later checked for possible improvement by linear programming.

We implemented a "Greedy Adding and Substitution" (GAS) heuristic based upon the methods that Church and ReVelle used to solve the original MCLP problem [11]. This heuristic first adds sites if they can improve coverage and then attempts to substitute other sites for those in the solution set if coverage can be further increased. The first site selected is that location which covers the largest fraction of the population without current access to a puesto. The algorithm picks as second site that village that covers the largest population not covered by the first site, and so on. It is possible that a site added to the solution set in an early iteration may not be justified later due to subsequent selection of villages as puestos. So, at each iteration, GAS tries to replace each village in the solution set one-at-a-time with a site not currently in the solution set. If improvement is possible, the puesto site chosen to replace a particular village is the one which gives the greatest improvement in the objective. If a tie occurs, the village with the lowest index number is selected. This process

TABLE 5
THE PUESTO SELECTION PROBLEM

Formulation	*Coefficient*	*Meaning*	*Data Required*
$\text{Max } Z = \sum_{i=1}^{m} a_i y_i$	a_i	population needing coverage at village i	population of each village in Zarzal; location of existing health centers
s.t. $\sum_{j=1}^{n} x_j - p = 0$	p	number of health centers	
$\sum_{j \in N_i} x_j - y_i \geq 0$	for all i		
$x_j = \begin{cases} 1 & \text{if a puesto is sited at village } j \\ 0 & \text{otherwise} \end{cases}$	for all j		
$y_i = \begin{cases} 1 & \text{when village } i \text{ is covered} \\ 0 & \text{otherwise} \end{cases}$	for all i		
Definitions:			
$N_i = \{D_i \cap A_i \cap R \cap W \cap E\}$	N_i	set of potential puesto sites that can cover village i	
$D_i = \{j \mid d_{ji} \leq s\}$	d_{ji}	shortest distance or time between site j and village i	distance/times of travel between every village in Zarzal
	s	limit on distance or time of travel	
$A_i = \{j \mid -30 \leq e_{ji} \leq 100\}$	e_{ji}	altitude change between site j and village i	altitude of every village in Zarzal
$R = \{j \mid j \text{ has no hospital}\}$			locations of hospitals in Zarzal
$W = \{j \mid j \text{ has acceptable water}\}$			villages that have acceptable water in Zarzal
$E = \{j \mid j \text{ has electricity}\}$			villages with electricity in Zarzal

is continued until either p villages have been chosen or all the population without current access to health centers can be covered.

From experience, we expected that (a) the GAS heuristic would generate an integer optimal solution about fifty percent of the time and (b) any non-optimal results would be no less than 90 percent of the optimal solution (in terms of coverage of the rural population) [11]. Three final GAS solutions were checked for potential improvement by attempting linear programming (LP) pivots. Each time the GAS result and the optimal solution were identical optimal integer solutions.[6]

PROMOTORA POLICY ANALYSIS

In order to determine whether this location analysis approach would be useful for puesto planning, we investigated

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6 The GAS runs were made using a Fortran IV program on the International Business Machines, Inc. (IBM) 370 system of the Health Service of the District of Bogotá. The attempted linear programming pivots used the IBM Mathematical Programming System (MPS) package installed on the IBM 360 system of the Universidad de los Andes in Bogotá. To compare the two, we ran both programs on the IBM 360/65 computer of the University of Tennessee at Knoxville, using a Fortran level G version of GAS and a MPSX version of the MCLP. A typical GAS run using the FASGAS program required 0.4 seconds per solution. The comparable MPSX performance was 1.5 seconds per solution.

three related issues. First, how does the covering model perform in comparison to the initial results of the Valle planners? Second, would covering results be useful for incremental puesto site selection? Third, could these analytical techniques indicate whether the Valle planners' detailed data requirements were really necessary prerequisites for determining health center sites?

Initial Siting of Health Centers

We decided to re-solve the Valle planners' question of the selection of sites for health centers in Zarzal. The Valle planners' results were illustrated in figure 2. This solution, as stated previously, is based upon judgement and partial application of the Valle planners' site restrictions. They would have liked to have determined health center sites using all the norms listed in table 2. By using GAS, we developed figure 3, which indicates the best possible sites, given all the restrictions. Only seven villages in all Zarzal are appropriate puesto sites.[7] If seven promotoras were recruited, one per health center, and each worked with 1000 persons, they

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7 Fifteen villages in Zarzal have both acceptable water and electricity. Seven of these were selected by GAS as potential sites; the other eight villages would be covered by those seven sites.

FIGURE 3
SITING WITH SIMULTANEOUS USE OF ALL RESTRICTIONS

Code

- * – county seat
- ● – village
- ■ – health center

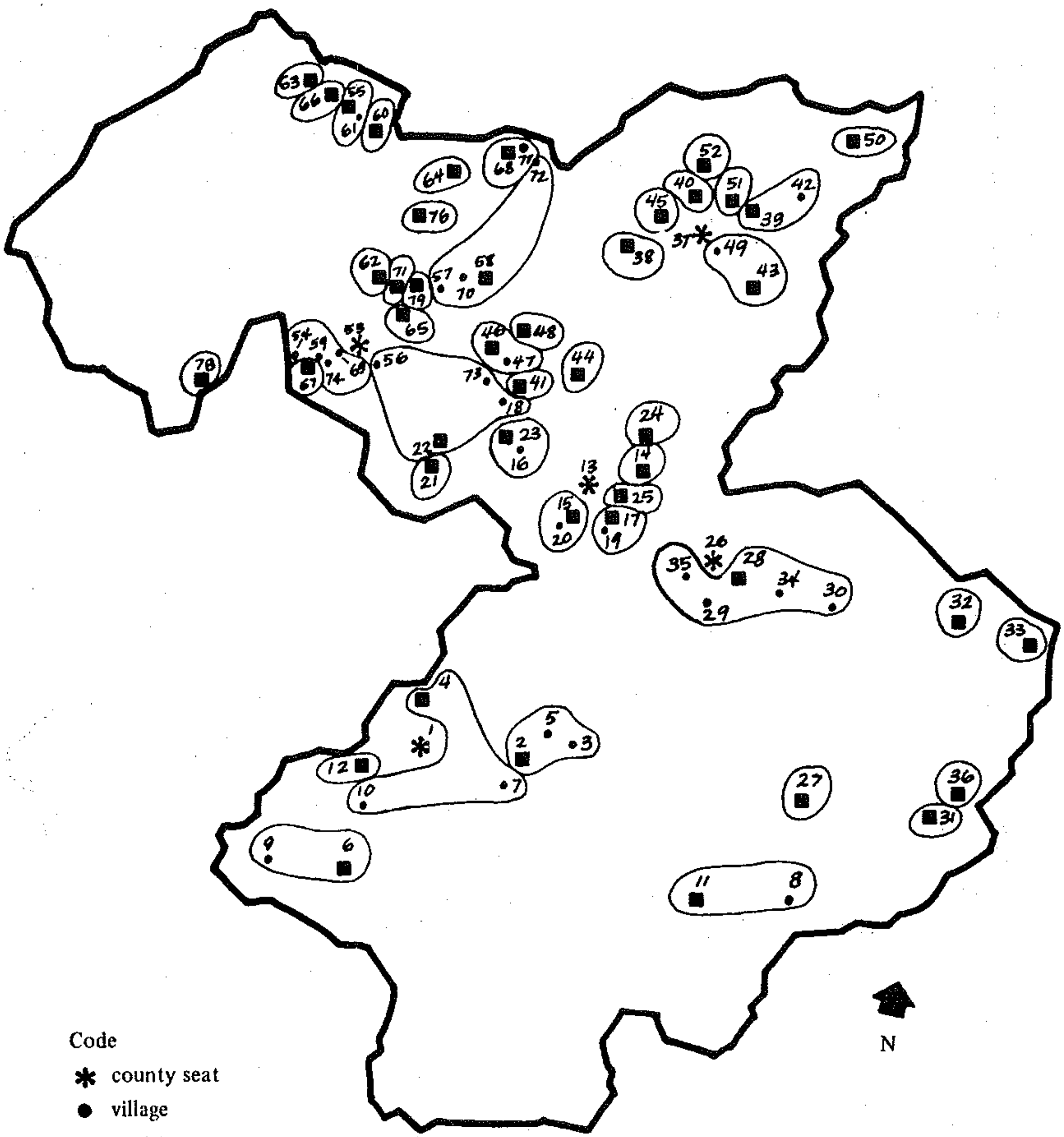
Numbers indicate village reference numbers

Enclosing circles indicate geographical service areas could reach only 24 percent of Zarzal's rural population. If each served all their villages' residents, they would cover 51 percent of Zarzal's rural population. This result was troubling, because it indicated that a strict application of all the norms led to a situation where the Service could not extend the health system into rural underserved areas.

Figure 4 shows those health centers from which promotoras would be recruited if acceptable water and electricity are not considered [i.e., travel allowed, subject to table 2 restrictions 1 through 3 only]. If the Ministry would deploy 55 promotoras at the 46 indicated puesto sites, promotoras could reach all the rural population. Figure 5 is another way to view this information; it shows the tradeoffs between the percent of the population covered and the number of health centers. The points show the highest levels of access possible for any given number of sites. The dashed line connecting these points is included to give the reader a sense for the decreasing marginal returns to new sites; the last 9 health centers increase coverage by less than 100 persons per puesto and the last 23 by fewer than 200 persons per site.

It is interesting to compare the 24 sites selected by the Valle planners and the first 15 selected by maximal covering (see table 6). The first fifteen sites selected by GAS are accessible to as many persons as the twenty-four sites selected by the Valle planners. Recall that the Valle planners

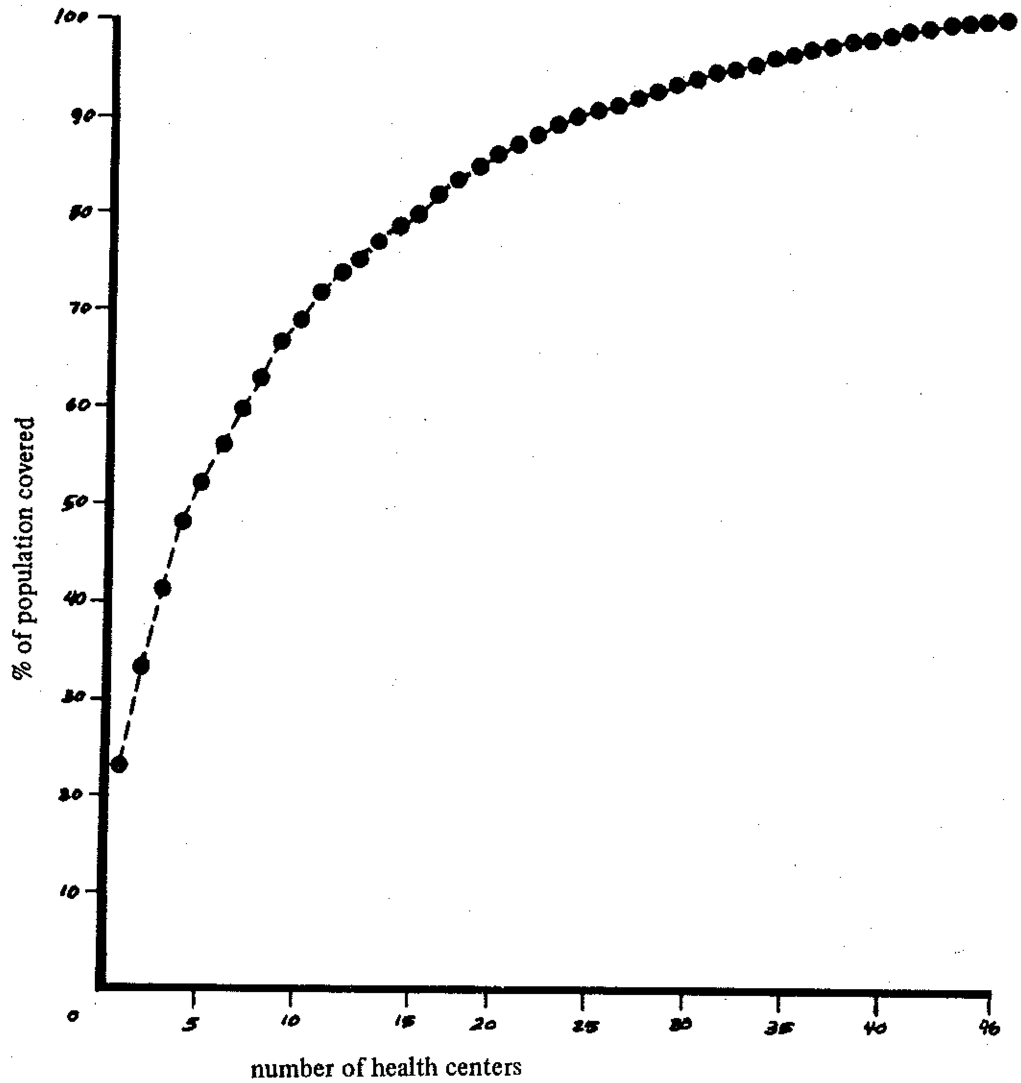
FIGURE 4
SITING WITHOUT THE ELECTRICITY AND WATER NORMS



Code
✱ county seat
● village
■ health center

Numbers indicate village reference numbers.
Enclosing shapes indicate geographical service areas.

FIGURE 5
SITING WITHOUT THE ELECTRICITY AND WATER NORMS: A TRADE-OFF CURVE



tried to select villages with acceptable water and electricity. The GAS runs, which locate health centers to cover population without concern for selecting sites with proper utilities, did nearly as well in absolute terms and better in relative terms in selecting villages with appropriate utilities. Table 7 lists the sites of the first twenty-four villages selected by GAS. Puestos in these villages could cover a larger fraction of the rural population than the planners' twenty-four sites. In short, maximal covering was found to select health centers that performed better, in the terms of reference of the Valle planners, than the sites selected by the planners themselves. This result reflects the complexity of the planners' plight - it is difficult to juggle in one mind seven items of information relating to seventy-four villages.

TABLE 6
COMPARISON OF HEALTH CENTER SITES

	Current Twenty-four Sites (selected by Valle planners)	*First Fifteen Optimal Sites (selected by GAS)*
Fraction of the rural population covered	78 %	79 %
Existence of acceptable water		
Fraction of sites	33.3%	40 %
Number of sites	8	6
Existence of electricity		
Fraction of sites	62.5%	86.7%
Number of sites	15	13
Existence of both acceptable water and electricity		
Fraction of sites	33.3 %	40 %
Number of sites	8	6

TABLE 7

LISTS OF HEALTH CENTER SITES*

24 Sites selected by Valle Planners

2	Alizal
5	Guasimal
6	La Paila
7	Limones
8	Quebradanueva
10	Uña de Gato
11	Vallejuelo
14	Corcega
16	El Rincón
19	Linderos
22	Quebradagrande
24	San Luis
30	Holguin
32	Miravalle
33	Riveralta
36	Taguales
39	El Bohio
49	San Antonio
50	San Francisco
52	Ventaquemada
57	Campoalegre
61	El Balsal
72	La Florida
78	Peñones

Portion of Rural Population Covered: 78%

First 24 Sites Scheduled by GAS

6	La Paila
28	El Guayabo
11	Vallejuelo
50	San Francisco
24	San Luis
39	El Bohio
32	Miravalle
58	Coconuco
55	Arenillo
22	Quebradagrande
23	Sabanazo
4	El Vergel
33	Riveralta
15	El Guasimo
14	Corcega

46	La Robleda
16	El Rincón
54	Altagracia
78	Peñones
2	Alizal
52	Ventaquemada
68	El Silencio
60	El Arbolito
65	El Diamante

Portion of Rural Population Covered by 15 Puestos: 79%

Portion of Rural Population Covered by 24 Puestos: 90%

*Numbers refer to village reference numbers.

Incremental Siting

Maximal covering was also used to investigate incremental health center placement - what should be the next puesto site, given that 24 villages have previously been selected. Table 8 is a list of the villages selected under different sets of assumptions. If all the ideal health center

TABLE 8
LIST OF HEALTH CENTER SITES FOR SYSTEM EXTENSION
(selected subject to all norms except as noted)

All Restrictions

*no.**	*village*
23	Sabanazo (La Unión)

added portion of rural population covered: 1.66%

All Except Water

*no.**	*village*
38	El Guayabo
15	El Guasimo
23	Sabanazo (La Unión)
69	El Tambo
65	El Diamante
58	Coconuco
41	El Cedro (Toro)
64	El Cedro (Versailles)
43	La Cayetana

added portion of rural population covered: 10.14%

All Except Electricity

*no.**	*village*
23	Sabanazo (La Unión)
54	Altagracia
	Murrapal
60	El Arbolito
	Puete Tierra
	El Rubí
	La Arabia

added portion of rural population covered: 6.26%

All Except Water and Electricity

*no.**	*village*
28	El Guayabo
15	Guasimo
23	Sabanazo (La Unión)
46	La Robleda
54	Altagracia
58	Coconuco
60	El Arbolito
65	El Diamante
31	La Hollanda
48	Sabanazo (Toro)
66	El Embal
21	Paramillo
41	El Cedro (Toro)
62	El Bosque
68	El Silencio
79	Puenta Tierra
63	El Cedral
76	Morroñato
27	Davila
44	La Chica
38	Chontaduro
45	La Quiebra
51	San Jose de Los Osos
67	El Rubí
25	San Rafael
12	Zambrano
71	La Arabia
64	El Cedro (Versailles)
40	El Bosque (Toro)
43	La Cayetana

added portion of rural population covered: 22.01%
(total coverage = 100%)

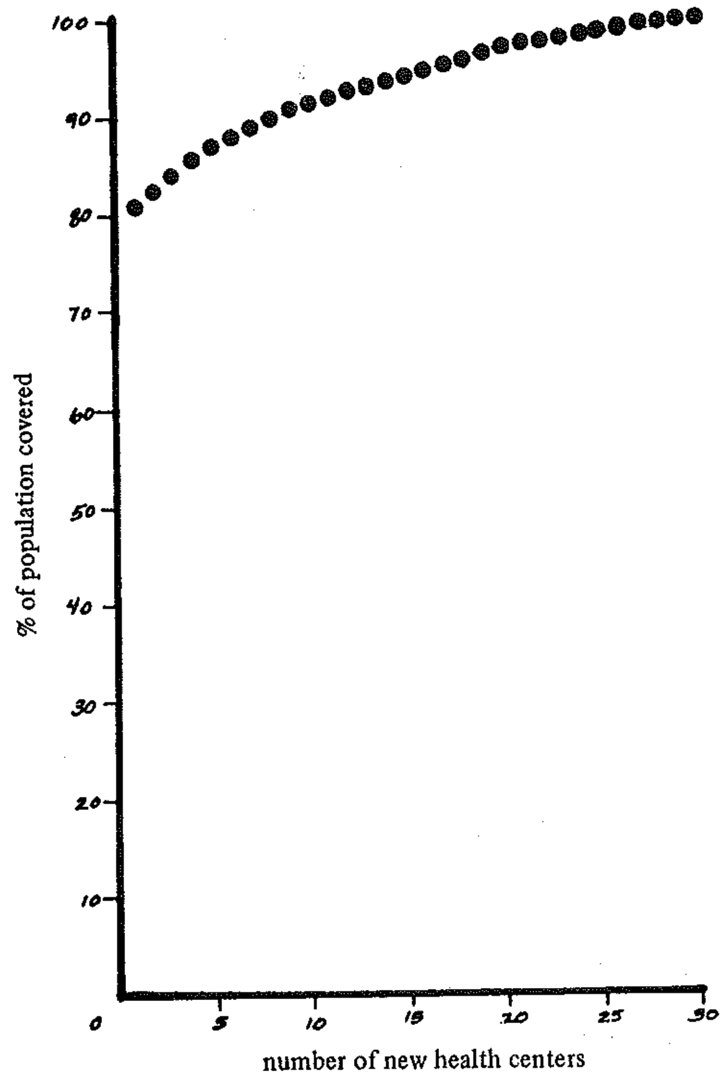
*Numbers refer to village reference numbers.

site norms (see table 2) are enforced, only one new village would be selected. This site is a village called Sabanazo (La Unión). If electricity supply is no longer required for potential sites, seven new villages could be selected. Eliminating water supply alone as a limiting factor for site location would allow planners to select any of nine new locations. If neither acceptable water nor electricity are considered as prerequisites, a planner can use GAS to determine thirty additional health centers that could cover all Zarzal's rural population. Certain villages, such as Sabanazo (La Unión) keep appearing in the solution set as good potential puesto sites. Such a robust result suggests that Sabanazo (La Unión) should be chosen as a health center.

Figure 6 shows the incremental coverage of added health centers. The twenty-four original sites are accessible to 78 percent of Zarzal's rural population. Twenty-three of the thirty new sites cover 200 or less incremental persons.

Both the "initial siting" and the "incremental siting" solutions indicate a paradox associated with the use of electricity supply and acceptable water as requirements of health centers. The use of these norms so restricts the number of potential sites that it is not possible to cover all the rural population with promotora service. Although water and electricity are helpful to a promotora's work, their absence does not seriously restrict promotion of health.

FIGURE 6
HEALTH CENTER EXTENSION USING FEW RESTRICTIONS: A TRADE-OFF CURVE



If water and electricity were not included as factors in determining potential promotora sites, it might not be necessary to conduct a sanitary survey in order to plan promotora deployment (see table 9). The locations of hospitals and current promotoras are on file in the State Health Service office. Village altitude and the time or distance of travel between adjacent villages could be measured in single visits to each village. Village population estimates, however faulty, do exist in state and national census data. One real value of the maximal covering approach is that it could be used in planning even without a survey. Of course, a field survey of sanitary conditions would provide more reliable information than existing files.

TABLE 9

DATA REQUIREMENTS AND SOURCES FOR HEALTH CENTER SITING – WITHOUT ELECTRICITY OR WATER NORMS

Item	*Data Source*	*Data Problems*
Location of hospitals	On file in any State Health Service office	None
Location of current promotoras	On file in any State Health Service office	None
Village altitude	Can be measured by travel to each village with altimeter	Altimeter may not be accurate
Time or distance of travel between adjacent villages	Distance can be measured by travel between adjacent villages with vehicle speedometer	Road distance may not accurately measure distance promotora must travel
	Time can be estimated from vehicle distances	Estimated time may not be accurate
Estimate of village populations	State or national census data	Census may not be complete or accurate

Regardless of the particular standards which planners may select to guide rural health extension, location analysis can assist them by inexpensively generating a list of sites that maximize the access of the rural population to promotora care either in unserved areas, where no health centers exist, or in underserved areas like Zarzal, where additional puestos will be added.

The results have illustrated that location analysis can be a useful adjunct to the judgement of the planner. Maximal covering is actually more useful than the original procedures of the Valle planners because (a) it can use data which either is readily available or involves a single visit to each village and (b) it can quantify the implications of the planners' value judgements.

THE RURAL MEDICAL VEHICLE LOCATION PROBLEM

We also wondered whether location analysis could assist planning for rural medical vehicle services. The issue is how to site vehicles to best achieve four incommensurate goals - material supply, medical supervision, doctor visitation, and patient transport. The local hospital is the major source for medical supplies because local markets sell only essentials [18]. One role of the rural medical vehicle is to move these supplies from hospitals to the promotoras and rural health centers.

Doctors travel from hospitals to rural health outposts for medical visits according to established timetables. Nurses regularly travel to villages to observe the promotoras and conduct in-service training. Such supervision is important in assuring effective performance because each promotora receives only three months of pre-service training [32]. Vehicles are also used to transport patients from villages, either upon referral from the promotora or during emergencies. When available, buses and private vehicles may also be used for medical transport [32].

Each of the regional and local hospitals in Zarzal have at least one medical vehicle. Each hospital operates its vehicle(s) independently, rather than as part of the regional health system. When a hospital's vehicle(s) are being repaired, there is no back-up system [18]. The Regional Health Unit does coordinate vehicle purchases and driver employment. The Valle Health Service purchases all vehicles[8], and bases them at hospitals [33]. The number of drivers is determined by a work-hour formula based on the hours needed to transport materials and move doctors and nurses, divided by the number of hours a driver may expect to be on-duty. Patient referral and emergency transfers are treated as

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8 Vehicles have been financed by several sources, including USAID, the Ministry, the Coffee Growers' Association, and the local residents themselves [19].

overtime driving that will be required but cannot be estimated.

If deployment is evaluated solely as movement of personnel and materials, then basing vehicles at hospitals is quite efficient. Any ambulance located at another site would first need to travel to the hospital to pick up the supplies or staff prior to leaving for the villages. Since the addition of a non-negative number (time from base to hospital) must exceed that response time alone, hospital location of medical vehicles minimizes average or maximal response time [9].

However, hospitals may not be the best sites to base medical vehicles that transport patients. Many American location studies, such as Savas [36] and Fitzsimmons [17], have found that non-hospital EMS vehicle sites are more accessible to calls than hospitals.

In order to test for possible improvements from the current vehicle configuration, the Valle planners suggested the introduction of regionalization and accessibility considerations into medical vehicle deployment. If the ambulance system were regional, rather than hospital-based, the Zarzal

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9 Response time is made up of two components, (a) the length of time for a driver to leave a hospital after a call is received and (b) the expected vehicle travel time from the hospital to the village. No information is collected on component (a). If driver preparation time can be described as a constant, then response time would be travel time plus the constant. The authors use travel time as a surrogate for response time.

Regional Health Unit would manage their use and distribution. One major operating change would be that vehicles could cross county lines during service.

To operationalize access, the Valle planners established a one hour response time as the surrogate for ambulance effectiveness [18][10]. The statement of the "patient transport" goal of the medical vehicle system becomes:

> Maximize the access within one hour of the rural population to transport service, by locating a fixed number of vehicles in the region.

A related problem discussed by ReVelle, et. al. [34] for EMS services was formulated as a maximal covering location problem. This problem can also be structured as a maximal covering location problem (see table 5) by allowing x_j to represent a decision to locate an ambulance at j or not, and y_i to be decision to cover village i or not. Also, let a_i equal the population needing coverage in village i and p be the number of vehicles to be sited. The set N_i, the potential vehicle sites that could cover village i, can be defined as:

$$N_i = \{ j \mid d_{ji} \leq s \} \qquad i = 1,2,\ldots,m \qquad (12)$$

where d_{ji} is the shortest travel time between potential site j and village i, and s, the upper bound on travel time, is equal to sixty minutes.

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[10] Response time is not the only and is perhaps not the best measure of accessibility. "Time to hospitalization" has been suggested as an alternative and has been used in an analysis in the Colombian context [18].

Figure 7 shows both the current hospital based vehicles (as squares) and also enclosing shapes that indicate the villages each ambulance can reach with one hour of one-way driving[11]. When vehicles can respond only to calls within the county, the system is accessible to approximately 93 percent of the rural population in Zarzal. Ambulances can cover such a large portion of the population because the five county seats lie in the valley. The villages have developed up the sides of the eastern and western ridges of the Andes, around the county seats.

We used GAS to generate a map showing the ambulance sites and their associated service areas that cover the largest fraction of the rural population within one hour (see figure 8). We also solved the problem with linear programming, and obtained an integer optimal solution identical to the GAS output. Vehicles based at five sites can reach all of Zarzal within one hour. Three of five optimal sites (nodes 26, 13, and 53) represent current hospital locations. The GAS solution also indicated that if the facility at node 55 were dropped out of the solution set, total system coverage would still be above 99 percent (all but 240 residents). This four vehicle solution covered a larger fraction of the rural population

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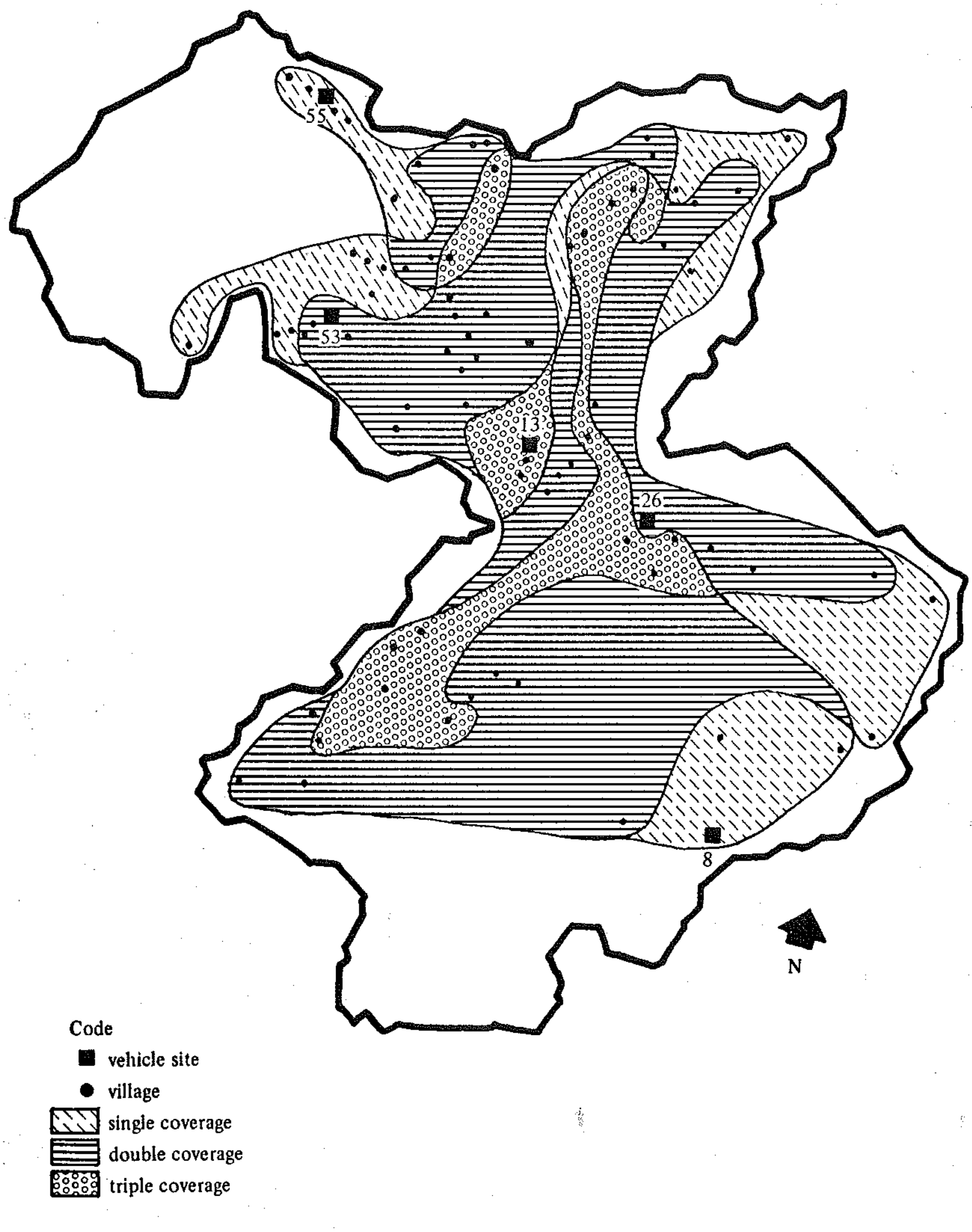
11 The shapes are drawn to indicate rough service areas of ambulances. Vehicles will not be able to reach points within these shapes that are not on roads.

FIGURE 7
COUNTY COVERAGE OF MEDICAL VEHICLES BASED AT HOSPITALS
(one hour response time)

■ vehicle site (hospitals in county seats)

• village

FIGURE 8
REGIONAL COVERAGE OF MEDICAL VEHICLES BASED AT OPTIMAL SITES
(one hour response time)



Numbers indicate village reference numbers.

in one hour than the present system with one fewer ambulance base . Thus GAS can suggest a deployment pattern that is both more accessible to potential patients and less costly, due to reduction of system operating costs by elimination of one vehicle base.

The overlapping service areas in figure 8 indicate a further advantage of a regional system - multiple coverage. Eighteen of the villages can be reached by vehicles at three sites in one hour and thirty-seven villages are covered by two vehicle bases. Twenty-four other villages can be reached from only one of the ambulance sites in an hour or less.

However, as long as rural health supervision, doctor visits, and supply goals are perceived as more important than patient referral or emergency medical service, it is unlikely that planners will want to eliminate or shift sites of medical vehicles. If the medical vehicle system's primary goal is to respond to materials and personnel transport needs of the hospitals in Zarzal, existing hospital-based vehicles cannot be better sited. This present ambulance system is also able to reach a large fraction of the demand for patient transport within standards established by the Valle planners.

Another way to realize marginal improvements in rural ambulance service would be to add additional vehicles to the current system. To address this extension issue, we fixed the current five bases and generated the locations of two additional sites that would enable all of Zarzal to be accessible to ambulance service in 60 minutes (villages 55 and 8). These locations are two of the five optimal vehicle sites in figure 8.

In summary, location analysis allows planners to both assess the performance of the current medical vehicle system and also determine good potential substitute or additional sites for ambulances. The hospital-based system of seven vehicle bases would not reach a larger fraction of the rural population in one hour than five vehicles located at the sites that maximize population coverage. In terms of foregone resources, "two sites" is a measure of the cost of maintaining the current hospital-based, non-regionalized policies of patient transport.

ON IMPLEMENTATION

This paper began with the observation that it is unusual for results from systems studies to be used and rare for such techniques to be transferred to ongoing planning efforts of operating agencies. Our experience has been that many of the problems that arise between formulation and

and implementation of plans are due to instability of the health sector and lack of coordination between levels of the health system. Because shifts in political leadership (through change of government or personnel) occur frequently, it can be difficult to implement multi-year plans. In addition, there can often be insufficient cooperation between those who operate health services, those who plan health systems, and those who determine health sector priorities.

We believe that this project illustrates what might be termed "appropriate systems analysis", and is the approach most likely to succeed in making the transition from paper to practice. The problem is defined by the local health planners. The systems technique uses information that can be gathered. The algorithms are comprehensible to local agency personnel and compatible with existing computer software. The results can be interpreted both in terms of the multiple goals of the agency managers and in the political and institutional context of Zarzal. The involvement of those who can use the results at each stage of this research process maximizes the likelihood that these tools will be utilized in Colombia to plan for the deployment of health resources in rural areas.

Due to the generosity of USAID and the Service, six health planners from Valle del Cauca came to The University of Texas at Austin for a month-long course on the application of location analysis to problems of deployment of health resources.

After returning to Valle, they have a produced a report describing their use of these methods in Zarzal [3]. More recent communications indicate that Colombians are utilizing some of the specific results reported here and are in the process of applying these techniques in areas other than Zarzal[12].

The puesto siting results have been applied with common sense in Zarzal. A promotora and health center have been added in Sabanazo (La Unión) due to its incremental coverage performance (see table 8). On the other hand, Patio Bonito (village 47) was selected as a site despite the fact that it appears on none of the lists and a neighboring village (La Robleda, village 46) is an early choice of the GAS algorithm as a site for itself and Patio Bonito. It turns out that La Robleda and Patio Bonito improve access for an equal number of persons. The GAS routine selected La Robleda due to its lower altitude. The local planner selected Patio Bonito because it is a larger village. El Guayabo (#28) and Guasimo (#15) were the top two GAS choices for new health center sites

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12 Discussions in July 1979 with Dr. Luis Fernando Cruz, Director of the Valle Servicio Seccional de Salud office in Zarzal, Dr. Himbad Gardner, Director of Health Planning for the Valle Servicio Seccional de Salud, and Dr. Carolina Navarette Hernandez, Chief of the Division of Programming and Evaluation, Colombian Ministry of Health.

(table 8); however, the planners believed that these villages are too close to their local hospitals (3.0 and 2.0 kilometers, respectively) to justify at this time the added expense of a health center.

Both general and specific recommendations regarding the rural ambulance system have been adopted in Zarzal. The rural medical vehicles are now managed on a regional, rather than a county basis. Due to the absence of prompt ambulance coverage in northwest Zarzal (figure 8), a decision was made to add a vehicle in El Balsal (village 61). Although Arenillo (site #55) was selected by maximal covering, planners recognized that a vehicle based at any of the uncovered villages would provide an equal level of incremental population access. El Balsal was chosen because it is larger than the other villages and, in addition, has electricity, potable water, a pharmacy, and an existing health center.

The Service has indicated that it plans to use the GAS program to screen potential health center and ambulance sites in Valle del Cauca areas other than Zarzal. As of September 1979, they were at the stage of keypunching data. Ministry staff have indicated an interest in applying these techniques in Santander, another Colombian state, but are still gathering the input data.

We also believe that this work has a value that transcends the specific application of methodology to a region in Colombia. We have become convinced that the use of maximal covering in conjunction with judgement is superior to the use of common sense alone in planning the deployment of rural health resources. Maximal covering location analysis can be quicker, less costly, less idiosyncratic, and more explicit than the judgement of planners. It allows people with different values and preferences to use the same information in making decisions. We believe that it can and will be used to allocate rural health workers and ambulance vehicles in other rural areas of Colombia and in other nations.

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