PLANNING AMBULANCE SERVICES FOR A RURAL EMERGENCY MEDICAL SERVICE DISTRICT

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Many private emergency medical service operators are discontinuing ambulance service, which the public sector then is forced to provide. Because of the high cost of providing emergency medical service, a large subsidy often is required which the public sector in many rural areas, already under severe financial stress, cannot afford. To assist in solving this problem, Oklahoma legislators passed a law in 1976 [6] which allows the formation of special emergency medical service districts. The usual procedure is for a district to be established along county lines. If the voters in the district approve support for an emergency medical service system, the district collects up to 3 mills annually from property owners to support the system. By October 1, 1977, voters of three counties in Oklahoma had approved creation of special emergency medical service districts. In addition, leaders of several other counties are discussing the issue and probably will take advantage of the enabling legislation.

After the voters approve a countywide system an advisory board is created which determines operating policies and procedures. This board often has many questions: How many ambulances should be provided? Where should they be located? What is the cost of each alternative? What is the quality of service for each alternative?

To the authors' knowledge, little research has been done on optimum location of ambulances in rural areas.[1] Sparse settlement patterns in rural areas make this a unique problem requiring analysis different from that used for urban problems.

The objective of this article is to develop and demonstrate a procedure which (1) determines optimum location(s) of various numbers of ambulance facilities under alternative objectives, (2) provides quality of service information for the location(s), and (3) provides budget estimates for ambulance facilities operated at the location(s).

THEORETICAL MODEL

The procedure merges the output of a transportation analysis and a budget analysis. The transportation analysis provides the policymaker with not only optimum locations, but also quality of service data (maximum and average response time) for each location. Budget analysis, conducted for each location selected by the transportation analysis, provides the policymaker with operating costs for each location. To our knowledge, this merger has not been achieved previously and it is very important to policymakers as they weigh the costs of additional facilities against improved quality of service provided.

THE GENERAL TRANSPORTATION MODEL

The transportation model [4] is used to optimize a linear objective function with respect to a specific type of constraint. In a generalized form, the model can be stated as follows.

M = number of possible locations of ambulance service facilities

n = number of locations of ambulance facility users

a_i = ambulance service capacity at the ith ambulance service facility

b_j = amount of ambulance services demanded by the jth location of ambulance service users

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[1]A summary of methods used for allocating urban emergency units is presented in [1]. In addition, Doeksen and Oehrtman [3] have completed research on location of rural fire trucks. That problem is different because a fire truck goes to the fire and returns to the fire station and an ambulance delivers patients to various locations inside and/or outside the district.

X_{ij} = amount of ambulance services to be supplied by the facility at location i to ambulance service users at location j

C_{ij} = "cost" of supplying one unit of ambulance service from ambulance facility location i to each user location j (one way miles were used as a proxy for "cost") and

$C_{ij}X_{ij}$ = cost of supplying X_{ij} units of ambulance services from ambulance facility location i to any user at location j.

The transportation problem can be stated in the following general mathematical relationships.

Minimize an objective function of the form

(1) $$z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}X_{ij}$$

subject to the constraints

(2) $$\sum_{j=1}^{n} X_{ij} = a_i, \qquad \text{where } i = 1,2...,m$$

(3) $$\sum_{i=1}^{m} X_{ij} = b_j, \qquad \text{where } j = 1,2...,n$$

(4) $$X_{ij} \geq 0$$

(5) $$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j.$$

The following assumptions must be satisfied before the transportation procedure can be used to solve either transportation problems or other kinds of problems.

1. Services being provided by each of the various facility location origins are homogeneous. In other words, availability of services at each origin will equally satisfy the demands in any service user location (equation 2).
2. Service capacities at various origins and demands at various locations of service users are known, and total demand must equal total capacity (equation 5). When discrepancies occur between service capacity and user demand, a dummy service capacity or user demand vector is used to produce equality. This dummy vector is used to signify unused capacities or unsatisfied demands.
3. Costs of providing services by any one origin to other locations of service users are known, and are independent of the amount of services provided. That is, there is a constant per unit cost of service provided between locations.
4. There is an objective function to be optimized (equation 1).
5. The activities cannot be executed at negative levels (equation 4).

Defining Objectives

Adequately defining objectives for location of emergency services probably has been the major obstacle to application of quantitative analysis to this type of problem. Because emergency services relate directly to protection of human lives, there is an absence of some overriding objective defining social utility. However, objectives used in this procedure are believed to approximate closely the thought process of service users, policymakers, and decisionmakers.

Two objectives were identified for use in the location analysis.

I. To minimize the maximum response time to reach an emergency, and
II. To minimize average response time to reach an emergency.

These objectives are based on the idea that service users, decisionmakers, and policymakers partially identify quality of emergency service with response time (i.e., the lower the response time, the higher the quality of service). The current emphasis in emergency medical service is to get trained emergency medical personnel to the patient and to stabilize the condition of the patient. The two objectives were designed to reflect these ideas and to also allow some quantifiable measure of quality.

Location Procedure

To adapt the general transportation procedure for use in this problem, certain modifications had to be made. When objective I was used, each location of ambulance facility user was given a value of 1 (i.e., $b_j = 1$ where $j=1,...,n$). This meant that an ambulance would have to make only one trip to each user location. The facility location(s) which had the smallest solution value (i.e., $\sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}X_{ij}$) represented the optimum solution and the location(s) which minimize the maximum response time. When objective II was considered, each location of ambulance facility user was given a value equal to the frequency of calls for ambulance service. This meant that an ambulance would travel to each user location as many times as necessary to handle the number of calls for each user location. The facility location(s) with the smallest solution value (i.e.,

$\sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}X_{ij}$) represented the optimum solution and the locations which minimized the average response time. Given that ambulances are to be placed in $K \leqslant m$ locations and given each objective, a complete enumeration of all possible combinations of m locations taken k at a time yields the optimum solution. The algorithm [5] provides the necessary data to derive maximum and average distances for each combination.

Budget Analysis

Budget analysis procedures were taken from a study by Doeksen, Frye, and Green [2]. The authors of that study developed procedures and forms to estimate ambulance calls, capital and operating costs, and revenues for an ambulance service area. The forms enable policymakers to adapt the procedure readily to their service area. Form I is used to estimate yearly ambulance calls and yearly mileage. Form II is used to estimate capital and operating costs. Form III summarizes costs of each alternative organization and location(s) considered and potential profit or loss for that alternative.

For each alternative location specified by the transportation model, a budget analysis was completed. Thus, the policymakers are provided with the costs of operation at each alternative location, and they can use this information in their attempt to provide the highest quality ambulance service within their budget constraint.

EMPIRICAL APPLICATION

The model was used in Latimer County, Oklahoma. The county is in the southeastern part of Oklahoma, and had a 1975 population of 9,800. Wilburton, the county seat, is the largest town in the county with approximately 3,000 population in 1975. The next largest town is Red Oak which had a 1975 population of 680.

Voters in Latimer County have approved a resolution to form an emergency medical service district along county lines, and to assess the maximum 3 mill levy. Currently, the ambulance service is being operated out of the Latimer County Hospital in Wilburton. With the additional revenue expected from the levy, the policymakers are considering alternative ambulance service organizations and locations. The policy board, county commissioners, and hospital administrator requested both location and budget analysis so that alternatives could be evaluated.

Location Analysis: Assumptions and Data

Latimer County policymakers were interested in evaluating five possible locations for the placement of as many as three ambulance facilities (i.e., m = 5): Buffalo Valley, Gowen, Red Oak, Wilburton, and Yanush (Figure 1).

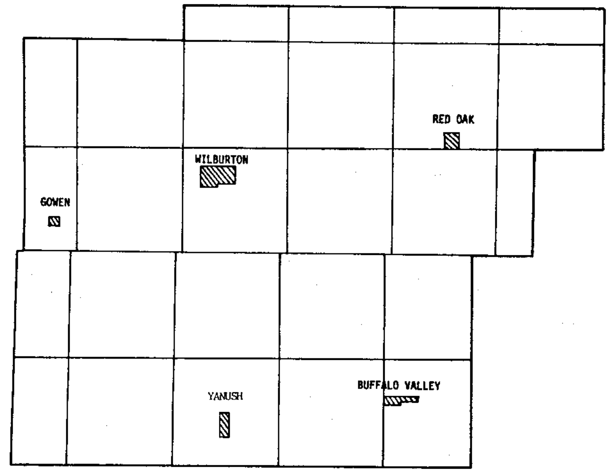

FIGURE 1. SUPPLY POINTS AND DEMAND AREAS, LATIMER COUNTY, OKLAHOMA

Once these possible supply points were designated, user locations or demand areas had to be delineated. This step was accomplished by following township lines within the county and 26 demand areas were created. Road miles from each of the five supply points to the center of each demand point were computed to determine the mileage matrix (C_{ij}). The only remaining information needed for the location model was the number of annual calls for ambulance service expected from each demand area.

Annual calls for ambulance service were divided into three types [2]. First, the total number of expected highway accident calls was estimated from highway injury accident data for the county. Thirty-five highway injury accidents were estimated to occur annually in the county. Second, transfer calls were estimated from data obtained from the current ambulance operator in the county. These calls reflect the movement of patients between hospitals. On the basis of these historical data, 33 transfer calls were expected to occur annually in the county. Finally, the annual number of other medical calls was estimated on the basis of the county population and the rate [2, p. 4] of calls per 1,000 population. Other medical calls include heart attacks, strokes, home and industrial accidents, and other health problems. The estimated number of other medical calls annually was 286. Thus, the total number of ambulance calls estimated for the county was 354.

Not all of these 354 ambulance calls were distributed among the 26 demand areas. The 33 transfer calls involve movement of patients from the county hospital at Wilburton to other hospitals. Thus, 321 ambulance calls were allocated among the 26 demand areas on the basis of the population of each area. This procedure yields a realistic estimate of the expected number of annual calls for ambulance service from each demand area.

Once the data items and assumptions of the location model had been satisfied, transportation problem solutions were derived for each objective in a complete enumeration of all possible combinations of locations. Specifically, the solution for each objective required that all possible combinations of transportation problems be computed for one, two, and three ambulance service facilities (locations), respectively. These combinations are $\binom{5}{1} = 5$, $\binom{5}{2} = 10$, and $\binom{5}{3} = 10$, or a total of 25 combinations of locations for each objective to be considered. Complete enumeration yielded 50 transportation problems, given the two different objectives considered in this study. These transportation problems were evaluated by use of the general linear programming transportation model.

Budget Analysis: Assumptions and Data

Procedures in [2] were used to estimate annual capital and operating expenses for each alternative location selected by the location analysis. However, cost data were updated to 1977 prices. In addition, a budget was devised to consider an alternative of locating two vehicles at Wilburton.

The following assumptions made for the budget analysis were believed to be realistic in terms of conditions in Latimer County.

1. Any ambulance at Wilburton would operate out of the hospital, and a building to house the ambulance is needed.

2. Any ambulance at the other supply points would operate out of volunteer fire departments, and volunteers would be on call and paid $5 per day. Two volunteers would be on call each day.

3. The communication system would operate out of Wilburton, and volunteers would have pagers.

4. Each ambulance would cost $16,350 and have a maximum life of 75,000 miles or 7 years, whichever comes first, and no salvage value.

Results

Results of these analyses are discussed in two parts. First, the locations selected by the location model and the quality of service variables for each location are presented. For each objective, the first and second choice solutions are given. First and second choice locations are sets of locations are shown so that policymakers have more information about alternatives. Second, the budget analysis showing the cost of operation from the selected locations is presented. This information on first and second choice location(s) allows policymakers to consider the costs of operation, small differences in quality of service, and political feasibility of alternative locations.

Optimum Location

Objective I: Location to Minimize the Maximum Response Time. First and second choice locations of one, two, or three ambulance facilities are shown in Table 1. Associated with each of these locations is a maximum and average per call distance (Table 2). For example, locating one ambulance in Wilburton and one in Yanush would result in a maximum distance to be traveled of 24 miles to reach the furthest emergency. The average distance per emergency with these locations would be 8.3 miles. The mileage figures can be considered as a quality of service indicator. If an ambulance is assumed to travel at 60 miles per hour, the maximum response time for these locations is 24 minutes. Depending on local conditions, other ambulance speeds can be used to convert miles to minutes.

Among first choice locations, the effect of one, two, or three locations on response time is to decrease maximum response time. Maximum response time decreases by 6 minutes when the number of ambulance locations is increased from one to two. A decrease of 3.5 minutes in response time is obtained if three ambulance locations are provided.

Objective II: Location to Minimize Average Response Time. For one ambulance location, the first choice is again Wilburton, whereas the second choice is Red Oak. For two locations, the first choice is Wilburton and Buffalo Valley, and for three locations the first choice is Buffalo Valley, Red Oak, and Wilburton. Average response decreases from 11 minutes to 8 minutes as the second vehicle is added, and decreases further to 6 minutes as the third vehicle is added.

TABLE 1. OPTIMUM LOCATIONS FOR VARIOUS NUMBERS OF AMBULANCE FACILITIES UNDER ALTERNATIVE OBJECTIVE FUNCTIONS

Objective and Number of Locations	------Choices------ First	Second
I. Minimize the maximum response time		
a. one ambulance facility	Wilburton	Buffalo Valley
b. two ambulance facilities	Wilburton, Yanush	Buffalo Valley, Wilburton
c. three ambulance facilities	Red Oak, Wilburton, Yanush	Buffalo Valley, Red Oak, Wilburton
II. Minimize average response time		
a. one ambulance facility	Wilburton	Red Oak
b. two ambulance facilities	Buffalo Valley Wilburton	Wilburton, Yanush
c. three ambulance facilities	Buffalo Valley, Red Oak, Wilburton	Red Oak, Wilburton, Yanush

TABLE 2. RESPONSE TIME IN MILES FOR VARIOUS NUMBERS OF AMBULANCE FACILITIES UNDER ALTERNATIVE OBJECTIVE FUNCTIONS

Objective and Number of Locations	------Choices------ First		Second	
	Maximum distance	Average distance	Maximum distance	Average distance
I. Minimize the maximum response time				
a. one ambulance facility	30.0	11.0	39.0	23.8
b. two ambulance facilities	24.0	8.3	25.5	8.0
c. three ambulance facilities	20.5	6.2	25.5	6.0
II. Minimize average response time				
a. one ambulance facility	30.0	11.0	45.0	18.2
b. two ambulance facilities	25.5	8.0	24.0	8.3
c. three ambulance facilities	25.5	6.0	20.5	6.2

Annual Costs of Operation

Capital costs are affected by the number of ambulances and type of ambulance facility. Operating costs are influenced by the number of calls, distance traveled, and labor arrangements. Thus, each location or combination of locations will have a different cost of operation. To give the policymakers in Latimer County additional information, annual budgets were estimated for each of the first and second choice sites selected by the location model (Table 3). In addition, a budget for two ambulances operating out of Wilburton is presented.

Very little difference in costs is seen between the first and second choices when two or three locations are considered. However, decision-makers can readily assess the cost of adding an additional facility. For example, yearly costs for one ambulance at Wilburton would be $43,038, whereas yearly costs would increase

TABLE 3. ESTIMATED ANNUAL BUDGETS FOR OPERATION OF ONE, TWO OR THREE AMBULANCES, 1977

Item	One Ambulance			Two Ambulances			Three Ambulances	
	Wilburton	Buffalo Valley	Red Oak	Wilburton, Yanush	Wilburton, Buffalo Valley	Wilburton	Red Oak Wilburton Yanush	Buffalo Valley Red Oak Wilburton
				Dollars				
Capital Costs:								
Vehicle	5,480	8,523	6,754	6,844	6,711	7,815	8,168	8,154
Communications	165	165	165	330	330	330	495	495
Pagers	0	0	0	200	200	200	400	400
Building	3,547	3,547	3,547	3,547	3,547	3,547	3,547	3,547
Interest	1,400	1,400	1,400	2,880	2,880	2,880	4,360	4,360
Sub-Total	10,592	13,635	11,866	13,801	13,668	14,772	16,970	16,956
Operating Costs:								
Gas	1,458	2,267	1,798	1,432	1,464	1,458	1,424	1,453
Vehicle maintenance[3/]	605	943	750	593	606	605	591	608
Base communications	252	252	252	252	252	252	252	252
Medical supplies	449	449	449	449	449	449	449	449
Building maintenance	900	900	900	1,350	1,350	900	1,800	1,800
Service contract	78	78	78	156	156	156	234	234
Labor	28,704	28,704	28,704	32,354	32,354	32,354	36,004	36,004
Sub-Total	32,446	33,593	32,931	36,586	36,580	36,174	40,755	40,801
Total	43,038	47,228	44,797	50,387	50,299	50,946	57,724	57,756

[3]Vehicle maintenance charge includes costs of oil changes, lubrication and other maintenance items.

to $50,299 if ambulances were located at Wilburton and Buffalo Valley.

Policymakers now can compare alternatives with respect to both the quality and cost of service with different numbers of facilities and locations. If only one ambulance facility and a minimization of maximum response time is desired, then Wilburton should be selected as the appropriate site. Maximum response time would be 30 minutes, and annual cost of operation would be $43,038. Any other choice could result in a longer response time and higher cost of operation with the same system. If two locations are desired, then the Wilburton and Yanush locations would minimize the maximum response time and would cost $50,387 to operate annually. The first choice locations to minimize average response time are Buffalo Valley and Wilburton, at an annual cost of $50,299. Thus, costs of operation are almost the same under either objective and location. However, two facilities cost approximately $7,000 more a year to operate than one facility. Quality of service is increased because maximum distance is decreased by about 5 miles, and average distance to an emergency is decreased by about 3 miles.

IMPLICATIONS

The empirical results illustrate the importance of long-range planning and careful consideration of objectives in capital outlay decisions about location of ambulances in rural areas. Optimum locations depend on whether policymakers decide to locate one, two, or three ambulances. Also, locations chosen depend on whether policymakers want to minimize the maximum response time or minimize average response time to reach an emergency. Quality and cost data are provided for each alternative location. Quality is reflected in maximum and average response times.

Similar analyses requested by leaders of other counties have been completed in approximately two weeks. This rapid response is possible because the transportation model is computerized. The most time consuming element is obtaining the local data.

We have found that the Latimer County case of planning ambulance service is not unique to that county. We are receiving a large number of requests for assistance from within Oklahoma and a large number of requests for publications from outside Oklahoma. The model discussed should have appeal for use in other areas. By adapting the model, policymakers can judge between costs and quality as indicated by the model, which should assist in final decisions.

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