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A GOAL PROGRAMMING MODEL FOR THE SITING OF MULTILEVEL EMS SYSTE--ETC(U)
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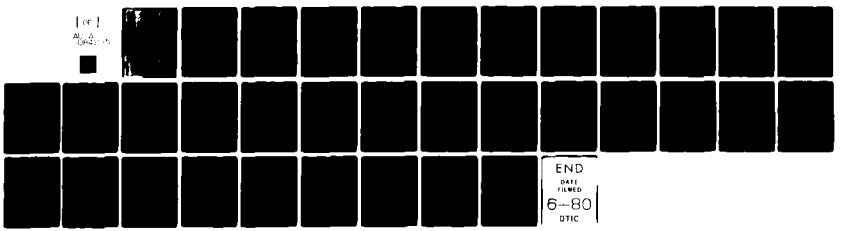

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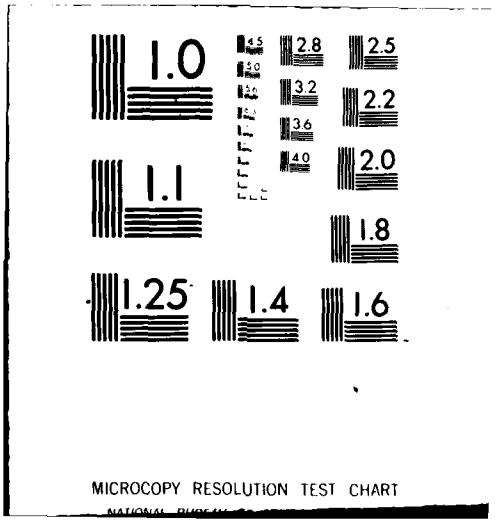
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Research Report CCS 366

A GOAL PROGRAMMING MODEL FOR THE SITING OF MULTILEVEL EMS SYSTEMS

by

A. Charnes
J. Storbeck

March 1980

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ABSTRACT

Facility siting models known as location covering techniques have proven to be useful particularly for emergency medical services (EMS) planning, given the importance of ambulances responding to demand within some maximum time constraint. These models represent a set of methods which focus the health planner's attention on the access of people to health care, since they attempt to "cover" people in need of service within some specified time standard.

This research develops a technique for the locational planning of sophisticated EMS systems, characterized by multiple levels of emergency health services. Specifically, a two-tiered system with "basic life support" and "advanced life support" capabilities is modeled as a goal program.

By applying location covering techniques within a goal programming framework, this study develops a method for the siting of multilevel EMS systems so that (1) each service level maximizes coverage of its own demand population, and (2) "back-up" coordination between levels is assured. The usefulness of this goal program as a health planning tool is evidenced in the model's explicit articulation of EMS policy objectives and its ability to link system levels in terms of "goal-directed behavior." The working of this multilevel covering model is demonstrated by reference to EMS planning scenarios and related numerical examples.

I. INTRODUCTION

Facility siting models known as location covering techniques represent a set of methods which can focus the analyst's attention on the access of people to health care. Work within this methodological framework has been carried out in a variety of public facility locational contexts. These models have proven to be useful formulations particularly for emergency medical services (EMS) planning, given the importance of ambulances responding to calls for service within some maximum time constraint.

Though the importance of the hierarchical concept in such social systems has been underlined in previous research, little use has been made of it in solving emergency health care delivery problems. Using a goal programming approach, this paper develops a multilevel covering model for the location of a hierarchical EMS system. This approach is appropriate for the modeling of such emergency medical systems as it seeks to provide the best possible access of the population to a number of types of health service.

Before turning to the development of the multilevel location covering approach, however, this paper first evaluates various methodologies in terms of emergency medical policy objectives. In this section, we attempt to construct realistic EMS palnning situations as the bases of evaluating the models to be presented. Secondly, this research discusses the significance of goal programming for public facility location modeling. Particular emphasis

in this discussion is placed upon the goal program as a methodology for incorporating behavioral mechanisms in location analysis. Futhermore, we attempt to demonstrate that one gains access to a broader range of locational policy alternatives by referencing the canonical form of goal programming. Finally, this paper develops a multilevel location covering model with behavioral linkages between levels of an EMS hierarchy. This methodology is then evaluated in terms of (i) its ability to address directly EMS policy objectives and (ii) its utility as an EMS management tool.

II. EMS POLICY AND MODELING FRAMEWORKS

Previous studies of the location of EMS vehicles have approached the situation within two broad policy frameworks. Works within one frame have addressed the question of determining the locations of the minimum number of vehicles needed for the operation of an EMS system, given certain demand levels and specific performance criteria. Works within the second frame, given the same demand and performance criteria cited above, have addressed the question of determining the best allocation of a specific number of available vehicles for the operation of the system.[1] The former framework, then, seeks to locate EMS units with no reference to the efficiency of such deployment schemes and carries with it the assumption that an EMS system has the available units to service all locations equally. How to allocate best fewer than this number of units is not considered. The latter approach,

however, addresses directly such issues as efficiency and effectiveness of service delivery in attempting to determine the best allocation of a limited number of EMS vehicles.

Notice that answers to questions posed within the first framework cannot help the analyst approach answers to questions within the second. The converse, however, is not true. That is, by varying the amount of given resources (vehicles) within the second frame, the analyst can in fact answer that which is posed within the first context. For this reason, we find the second policy framework, that of attempting to efficiently allocate a limited number of units, the most useful and realistic approach to the deployment of EMS vehicles.

The adoption of the above policy framework leads us to questions concerning the type of location analysis to be undertaken. Since we are interested in allocating scarce resources in a spatial setting, we might ask whether we are attempting to service locations (i.e., points in space) or demand which occurs at locations.[2] The distinction posed by this question is not trivial, since we would like to have a sound basis for judging the performance of one allocation scheme against that of another. Moreover, this distinction gains added significance in the EMS context due to the oft times <u>critical</u> nature of calls for service. Thus, the latter locational focus, that of servicing demand which occurs at locations, is the one which is undertaken in this investigation.

Given the adoption of the above frameworks, then, this research now approaches planning situations common to many EMS systems. In general, we wish to locate EMS vehicles (ambulances) so that a maximum number of calls for service are "covered" within some time standard, say T minutes, assuming a specific number of ambulances are available. In such a scenario, coverage of calls occuring at any location is defined in terms of that location's proximity to an ambulance site. Specifically, if some location i is within T minutes of ambulance site j, the call for service at location i is considered "covered" by site j. If, on the other hand, location i is beyond T minutes of site j, demand for service at that point remains "uncovered." Our purpose in this situation is to site all available EMS vehicles in such a way that a maximum number of emergency calls are covered within T minutes. The primary focus of our model, then, is upon behavioral constructs. We are concerned not with facility placement per se, but with the resulting coverage patterns.

In an attempt to build upon the strengths of behaviorally-oriented location models, this paper now turns to the consideration of an explicit goal program for covering methodologies. The following section, in fact, presents a general goal programming context for location covering analysis. Moreover, a model for the covering of several types of demand for emergency care by a hierarchical EMS system is developed as a multilevel extension of this behavioral outlook.

III. GOAL-ORIENTED LOCATION COVERING

Goal programming is a methodology which has been in use since 1952 and has already been applied in countless studies of both private and public sector situations (1,2,3,4,6,7,8). Indeed, many recent applications of this analytic technique have been associated with the multiobjective orientation of what Charnes and Cooper (3) have called "public management science." In this context, we propose a return to the canonical form of goal programming for the modeling of location covering. Though certain programming formulations of specific covering situations have in fact been in the form of goal programs (9,11), we believe that this proposed return to the canonical form of goal analysis will extend the notion of location covering and provide access to the solution of related problems. Key among these extensions is the covering of a number of classes of demand by a multilevel EMS system. Thus, we proceed by first briefly introducing the mathematical form of the goal program for a simple class of such programs. Then a general location covering formulation, modeled as a goal program, is proposed. Furthermore, this model's relationship to other covering models is demonstrated. Finally, a multilevel covering model is developed and discussed within an EMS context.

Goal Programming

Let us suppose that we have m goals which can be expressed by an m-component column vector g. Let us also assume that these

goal levels can be attained by linear combinations of the n subgoal variables represented by an n-component column vector x. If A is an m x n matrix of technological coefficients representing the relationships between goals and subgoals, then we can express our problem of attempting to attain these goals as

$$\text{Minimize} \qquad ey^{+} + ey^{-} \tag{1a}$$

subject to

$$Ax - Iy^{+} + Iy^{-} = g \tag{1b}$$

$$x , y^{+} , y^{-} \geq 0 \tag{1c}$$

where e is the m-component row vector whose elements are all equal to 1, y^{+} and y^{-} are m-component column vectors for the respective deviations over and under the goal vector g, and I is the m-dimensional identity matrix.

It should be noted that the "goal functional" represented by (1a) is only the very simplest type of goal functional. For more general types and conditions under which they are relevant, see, for example, "Explicit Solutions in Convex Goal Programming" (5), and "A Goal Interval Programming Model for Resource Allocation in a Marine Environmental Protection Program" (4). The latter type of functional, the "goal-interval" functional, is particularly useful when goals are "satisficing" or "fuzzy" in

that any point in the interval represents equally good performance. It should be noted that, contrary to erroneous remarks in the goal programming literature, such functionals were already contained in the developments in (2).

Note that constraint set (1b) expresses the relationship between goals and subgoals. The objective function (1a) seeks to minimize the amount of deviation from these goals. Notice, however, that this program does not require that all goals be attained. Though we are attempting to drive all y^+ and y^- values to zero, we can have solutions where some y^+ or y^- values are greater than zero. In such cases, we have deviated from an unattainable goal. The fact that program (1) allows an optimal solution which is "as close as possible" to the goal vector, albeit unattained, emphasizes the satisficing nature of the model (14). This characteristic of goal programming formulations can be quite useful in the modeling of public sector allocation problems, where system goals might be tightly constrained by limited resources.

Before turning to the specifics of location covering, we should further note the flexibility of goal programs in the possible variations in the functional. A number of different versions of program (1) can be formed by changing the signs of y^+ and y^- in (1a) or by dropping one of these vectors from the objective function. Ijiri (12) has examined the results, in terms of both goal and subgoal values, of adopting each of these possible variations on

goal analysis. We will return to this topic shortly in our discussion of the "maximal covering" approach as a form of covering analysis which has used this strategy.

We should also point out that the goal deviations, y^+ and y^-, may be weighted in a relative, a preemptive, a combined relative-preemptive fashion, or other non-linear weighting formats such as "goal-intervals." These weighting schemes have the effect of ordering our consideration of deviations from the desired goals and address the question of commensurability of goals (3,12). The working of this ordering process will become apparent in the development of models which follow.

A General Location Covering Form

Let us now take the canonical form of program (1) and develop a general location covering approach within the goal programming context. Our hope is to formulate a model which can be easily modified for different planning scenarios and which will give ready access to efficient computational forms.

Returning to the situations posed in previous covering research, let us assume that we have a region characterized by n nodes of a network, that demand for service occurs at each of these nodes, and that we have recorded representative travel times from each node in the region to each other node. Furthermore, as providers of emergency medical services, we wish to

deploy ambulance units of an EMS system in such a way as to cover demand within T time units. We must also realize that we have only p ambulance units available. A goal-oriented location covering (GLC) statement of this general situation might be

$$\text{Minimize} \quad \sum_{i \in I} - y_i^+ + y_i^- \tag{2a}$$

subject to

$$\sum_{j \in J} a_{ij} x_j - y_i^+ + y_i^- = 1 , \quad i=1,\ldots,n \tag{2b}$$

$$\sum_{j \in J} x_j = p \tag{2c}$$

$$x_j , y_i^- = (0,1) \text{ for all } i, j \tag{2d}$$

$$y_i^+ \geq 0 \quad \text{for all } i \tag{2e}$$

where I = the index set of demand nodes i

J = the index set of possible vehicle sites j

p = the number of available EMS vehicles

x_j = 1 if a vehicle is sited at j
0 otherwise

a_{ij} = 1 if travel time (d_{ij}) from j to i is less than T
0 otherwise

y_i^+ = the over-attainment of the covering goal at location i

y_i^- = the under-attainment of covering at location i.

Now, program (2) is similar to program (1), except that the sign of the y_i^+ term in the objective (2a) is negative. Recall that this difference between the two program forms is one of the possible variations of a goal programming functional mentioned previously. Minimization of a functional such as (2a) which has a negative sign on the y_i^+ term has the effect of maximizing Ax in the constraint set. For program (2), then, the minimization of (2a) produces a maximization of the $\Sigma a_{ij}x_j$ in constraints (2b).

Note the correspondences between the GLC model of program (2) and previous locational formulations. The so-called "maximal covering location" model (9), for example, attempts to minimize a form of under-attainment, having dropped the over-attainment vector from the functional. *The GLC model, however, combines both sides of the* "coverage coin" in its return to the canonical form of goal analysis with deviations above and below covering goals. Thus, with only simple changes in (2a) via permissable weighting schemes, GLC can easily consider the issue of maximal coverage of demand. Moreover, the GLC approach to covering gives access to an important class of locational planning scenarios which are hierarchical in nature. Since such situations are becoming increasingly important to EMS planning, we now turn to the consideration of multilevel covering. For ease of exposition and to facilitate comparisons with previous research, the over-attainment vectors will be deleted from the functionals of the models below, though they will remain a part of the constraint sets. In so doing, we are at this time considering only a limited class of covering models which minimize under-attainment deviations.

A Multilevel GLC Model

The previous model of location covering addressed situations in which there exists but one class of demand and one type of service. In reality, EMS systems often face many types of demand for service and provide a number of levels of emergency care. The following analysis considers such hierarchical situations.

Suppose we have two broad categories of demand, critical and non-critical. The former group would contain those calls for service which might be considered "life threatening" situations; the latter group would contain those calls which are of an emergent nature, though they would not be considered "life threatening." Let us suppose that the EMS system offers two levels of service, "advanced life support" (ALS) and "basic life support" (BLS). The ALS service is provided by paramedic units, which are equipped to effectively handle critical demand. BLS services are provided by emergency medical technician (EMT) units, which are best equipped to answer non-critical calls. Finally, let us assume that though EMT units are not equipped with ALS capabilities, there does exist an ancillary role for these units in terms of responding to critical calls. In lieu of immediate paramedic assistance, there are regular first-aid procedures which can be performed by EMT units in critical situations until ALS-equipped vehicles arrive. These situations, then, necessitate the definition of a "back-up" function for EMT units.

Now, the locational modeling of such an EMS system must explicitly consider the structure of the organization, since services in this case are provided "in parallel" and "in sequence." In the former case, ALS and BLS services are offered by two distinct levels, paramedic and EMT units, respectively. In the latter case, first-aid services are offered by EMT units to certain critical calls until a paramedic unit arrives and provides ALS services. Such an organizational structure somewhat complicates the modeling effort, since we are faced with a system which is not "purely pyramidal."[3] Let us begin this effort, then, by first considering the "back-up" function and the coverage of critical demand.

The situation which is of interest at this point is the coverage of critical demand by paramedic and EMT units, or ALS and BLS units, respectively. Now, consider again a region where critical demand for EMS is distributed spatially and represented at n points. We wish to deploy ALS ambulances and BLS ambulances in such a way as to cover this critical demand within T time units. Furthermore, since ALS vehicles are more appropriately equipped for this task, we seek to maximize primarily their coverage of these critical calls; BLS vehicles are serving only a "back-up" function.

The mathematical expression for the above EMS scenario might take the goal programming form

$$\text{Minimize} \quad \sum_{i \in I} c_i y_i^{\alpha-} + c_i y_i^{\beta-} \tag{3a}$$

subject to

$$\sum_{j \in J} a_{ij} x_j^1 - y_i^{\alpha+} + y_i^{\alpha-} = 1, \; i=1,\ldots,n \tag{3b}$$

$$\sum_{j \in J} a_{ij} x_j^2 - y_i^{\alpha-} - y_i^{\beta+} + y_i^{\beta-} = 0, \; i=1,\ldots,n \tag{3c}$$

$$\sum_{j \in J} x_j^1 = p^1 \tag{3d}$$

$$\sum_{j \in J} x_j^2 = p^2 \tag{3e}$$

$$x_j^1 , x_j^2 , y_i^{\alpha-} , y_i^{\beta-} = (0,1), \text{ all } i, \text{ all } j \tag{3f}$$

$$y_i^{\alpha+} , y_i^{\beta+} \geq 0 , \text{ all } i \tag{3g}$$

where p^1 = the number of available ALS vehicles

p^2 = the number of available BLS vehicles

c_i = the relative frequency of critical demand at location i

x_j^1 = 1 if an ALS vehicle is sited at j
0 otherwise

x_j^2 = 1 if a BLS vehicle is sited at j
0 otherwise

$y_i^{\alpha+}$ = the over-attainment of ALS coverage of location i (i.e., the number of ALS vehicles greater than 1 which are covering i)

$y_i^{\beta+}$ = the over-attainment of BLS coverage of location i

$y_i^{\alpha-}$ = 1 if the coverage of i by ALS units is under-attained
0 otherwise

$y_i^{\beta-}$ = 1 if the coverage of i by BLS units is under-attained
0 otherwise.

Constraints (3d) and (3e) give the number of available ALS and BLS ambulances, respectively. Notice that constraint set (3b), similar to (2b), defines coverage of critical demand at all nodes i by ALS units. According to this relation, at least one vehicle will be sited to cover node i (i.e., at least one x_j^1 in the i^{th} constraint will equal 1) only when the corresponding $y_i^{\alpha-}$ is driven to zero. In such cases, then, node i will be considered covered. Note that when more than one ALS unit is within T minutes of node i, the corresponding $y_i^{\alpha+}$ will take on positive values. Constraint set (3c) defines the "back-up" coverage of critical demand by BLS units. These constraints are similar to those of (3b), except that x_j^2 vehicle sitings are being made. The $y_i^{\alpha-}$ vector, appearing in (3b) and (3c), plays a double role in this model. In constraints (3b), $y_i^{\alpha-}$ represents critical coverage under-attainment for nodes i by ALS units; in (3c), the same variable is used to "activate" the siting of BLS vehicles to cover critical calls at nodes i. Notice that the value of the right-hand side of (3c) is zero, which suggests that the "back-up" coverage function is not activated until $y_i^{\alpha-}$ is equal to 1. Casting this role in terms of EMS policy, we are able to drive $y_i^{\alpha-}$ to zero when we are able to cover node i with an ALS unit, and our coverage goal at the (3b) level has been attained. However, when we are not able to cover i with an ALS vehicle, $y_i^{\alpha-}$ equals one and the (3b) coverage goal is under-attained. Consequently, this failure to meet the ALS level coverage goal

for node i suggests the possibility of a "back-up" siting of a BLS unit by means of relation (3c).

The objective function (3a) minimizes the relative frequency of critical coverage under-attainment by ALS units and by BLS units. That is, the objective in (3a) can be interpreted as minimizing the expected (or mean) value of under-coverage of critical demands. With such a weighting scheme in the functional, program (3) takes on a "maximal covering" location structure for two levels of facilities. Moreover, one could also guide the minimization of coverage deviations by using the preemptive methods discussed earlier. For example, if one were to multiply the $y_i^{\alpha-}$ in (3a) by a "non-Archimedean" weight, one would in effect set up a two-stage optimization process where the first term of the functional is minimized before the remaining two terms.

At this point, let us consider the addition of non-critical demand to the planning scenario. Now, the EMS system must provide coverage of critical calls as well as that of non-critical calls for service. The coverage of two different types of calls, then, suggests two response time standards, T^1 for covering critical calls and T^2 for covering non-critical calls. Consequently, these response standards become the bases for defining the respective covering coefficients, a_{ij}^1 and a_{ij}^2 .

Thus, the BLS units in the above system are assigned two tasks, that of providing "back-up" coverage of critical demand and that of providing coverage of non-critical demand. We formulate this situation as

$$\text{Minimize} \quad \sum_{i \in I} c_i^1 y_i^{\alpha-} + c_i^1 y_i^{\beta-} + c_i^2 y_i^{\theta-} \qquad (4a)$$

subject to

$$\sum_{j \in J} a_{ij}^1 x_j^1 - y_i^{\alpha+} + y_i^{\alpha-} = 1, \text{ all } i \qquad (4b)$$

$$\sum_{j \in J} a_{ij}^1 x_j^2 - y_i^{\alpha-} - y_i^{\beta+} + y_i^{\beta-} = 0, \text{ all } i \qquad (4c)$$

$$\sum_{j \in J} a_{ij}^2 x_j^2 - y_i^{\theta+} + y_i^{\theta-} = 1, \text{ all } i \qquad (4d)$$

$$\sum_{j \in J} x_j^1 = p^1 \qquad (4e)$$

$$\sum_{j \in J} x_j^2 = p^2 \qquad (4f)$$

$$x_j^1 , x_j^2 , y_i^{\alpha-} , y_i^{\beta-} , y_i^{\theta-} = (0,1), \text{ all } i,j \qquad (4g)$$

$$y_i^{\alpha+} , y_i^{\beta+} , y_i^{\theta+} \geq 0, \text{ all } i \qquad (4h)$$

where c_i^1 = the relative frequency of critical calls at i

c_i^2 = the relative frequency of non-critical calls at i

a_{ij}^1 = 1 if $d_{ij} \leq T^1$
0 otherwise

a_{ij}^2 = 1 if $d_{ij} \leq T^2$
0 otherwise

$y_i^{\theta+}$ = the over-attainment of BLS cover of <u>non-critical</u> calls at location i

$y_i^{\theta-}$ = 1 if coverage of non-critical calls at i is under-attained by BLS units
0 otherwise

and all other notation is defined as in program (3).

Note the addition of the constraints (4d), which define non-critical coverage by BLS units. As in previous programs, constraint sets such as (4b) define the coverage of critical calls by ALS units, while relations such as (4c) provide the "back-up" coverage of critical demand by BLS units. Constraints (4e) and (4f) give the number of available ALS and BLS ambulances, respectively.

It is interesting to note that the omission of the (4c) constraint set (and the elimination of the $y_i^{\beta-}$ vector from the functional) would simply create an EMS system offering two services "in parallel." As presently constituted, however, the objective function (4a) minimizes three coverage under-attainment vectors and, consequently, is of the "maximal covering" form. Specifically, the functional attempts to provide a maximal cover of critical calls by ALS and BLS vehicles, plus a maximal cover of non-critical calls by BLS vehicles.

IV. NUMERICAL EXAMPLE

Consider a region where demand for EMS is recorded at sixteen nodes (Figure 1). Calls for service can be classified as either critical or non-critical and occur in terms of the relative frequencies listed in Table 1. The maximum time standard within which we would like vehicles to respond is four minutes. This response standard, in this case, applies to both services and both types of calls. (Thus, we define $T^1 \equiv T^2 \equiv 4$ minutes.)

Table 2 shows "maximal covering" solutions (i.e., those which minimize under-attainment of coverage) which can be obtained with the application of versions of the GLC model of program (2). Notice that these results relate to single level systems. That is, the solutions offered in Table 2 for various numbers of vehicles represent the coverage of critical calls solely by ALS units and the coverage of non-critical calls solely by BLS units. When these vehicles are deployed in this manner, the EMS system under study is offering the two levels of service strictly in parallel. Such a deployment strategy makes no reference to a significant "back-up" function by the BLS level.

Suppose, for example, that one is faced with a system of four ALS vehicles and four BLS vehicles. If the units are deployed by the above strategy (i.e., no explicit reference to "back-up"), the separate locational configurations for each of the two levels are highly similar (see Figures 2 and 3).[4] For instance, Figure 2 shows that ALS vehicles sited at nodes 1, 5, 10, and 13 offer the least number of critical calls left "uncovered." Figure 3 shows that BLS sites at nodes 1, 5, 9, and 13 offer the best coverage of non-critical calls. If these siting configurations were incorporated into one EMS system where "back-up" concerns were prevalent, however, such a deployment pattern would be inappropriate, since the degree

of critical call coverage would be extended by only 6 percent. Specifically, the BLS vehicle sited at node 9, covering nodes 9 and 11, would be the only EMT unit to provide additional coverage of those crtical calls not already covered by ALS units. This relatively small increase in critical coverage by four possible "back-up" units would be due to the occurrence of multiple sitings of units at three locations.

If, however, the coverage goals of these two levels of service were coordinated, the resulting configuration would be quite different. Figure 4, for example, displays the siting of ALS and BLS units in a system where the "back-up" function entered explicitly into the modeling process. This configuration, in fact, represents the locational solution to the above planning scenario by employing the MGLC model of program (4). Notice that the solution has only one multiple siting of vehicles at node 13. The remaining BLS units at nodes 6, 9, and 14 have extended the original critical call coverage from 84% by ALS units to 100% by both levels. Thus, by applying the MGLC model, we have provided a substantial "back-up" capability in the coordination of this multilevel EMS system.

In this case, preemptive weights were used to guide the optimization process so that the three coverage goals were considered sequentially. That is, the under-attainment of critical coverage by ALS vehicles was minimized first, the under-attainment

of critical coverage by BLS units was minimized second, and the under-attainment of non-critical coverage by BLS units was minimized last. Though we have found the strategy of considering this particular sequence of goals compelling in such EMS systems, it is by no means necessary for the functioning of this deployment model.

V. SUMMARY AND CONCLUSIONS

Program (4) can be seen as a multilevel, goal-oriented location covering (MGLC) model which maximizes coverage of two types of demand. The formulation presented in this paper is a two-level, three-objective extension of the GLC approach. Similar extensions to EMS systems of more than two levels are possible without change in form.

In a return to the canonical form of goal analysis, we have developed a location covering modeling context for the deployment of multilevel EMS systems responding to more than one class of emergency demand. Furthermore, framed as a complete goal program, this modeling effort has emphasized the behavioral aspects of such planning scenarios. Indeed, linkage between levels of an EMS hierarchy was made in terms of behavioral constructs. That is, the "goal-directed behavior" of one service level was directly related to the "goal-directed behavior" of another level. In the MGLC model, this relationship was expressed by the explicit reference of a single coverage under-attainment vector to two levels

of EMS service. In EMS policy terms, this relationship was expressed by the "back-up" function served by the BLS vehicles.

Future extensions of this goal programming approach to multilevel location covering will address crucial issues which were left unanswered in this short exposition. Concern for situations characterized by the realities of the uncertain emergency medical environment has suggested formulations in the areas of goal-interval and chance-constrained programming. Moreover, recognizing the need for efficient computational forms, we are currently developing model equivalents in a "distributional" context.

NOTES

1 For a comprehensive review of the development and application of location analytic models for EMS siting, see (16). For a more general review of location models in private and public sector systems, see (15).

2 See (16) for an excellent discourse on the differences between the so-called "set covering" and "maximal covering" location models in an EMS policy setting.

3 See (10) for a discussion of the implications of such structures for planning scenarios.

4 ALS and BLS sites in all figures are denoted by "A" and "B" characters, respectively. ALS coverage is represented by dashed line enclosures; BLS coverage is represented by stippled line enclosures.

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TABLE 1

Relative Frequencies of Demand
for Sixteen Node Region

Node Number	(Relative Frequencies) Critical	Non-critical
1	.14	.05
2	.10	.05
3	.07	.06
4	.03	.09
5	.05	.06
6	.11	.04
7	.17	.05
8	.05	.04
9	.03	.08
10	.02	.06
11	.03	.11
12	.03	.06
13	.02	.04
14	.05	.05
15	.02	.11
16	.08	.05

TABLE 2

"Maximal Cover" Solutions for Single EMS Levels
(T = 4 minutes)

# ALS Units	Locations (Node Nos.)	Percent Cover
1	1	41
2	1 , 5	67
3	1 , 5 , 10	77
4	1 , 5 , 10 , 13	84
5	1 , 5 , 9 , 10 , 13	90
6	1 , 5 , 9 , 10 , 13 , 14	95
7	1 , 5 , 8 , 9 , 10 , 13 , 14	100

= = = =

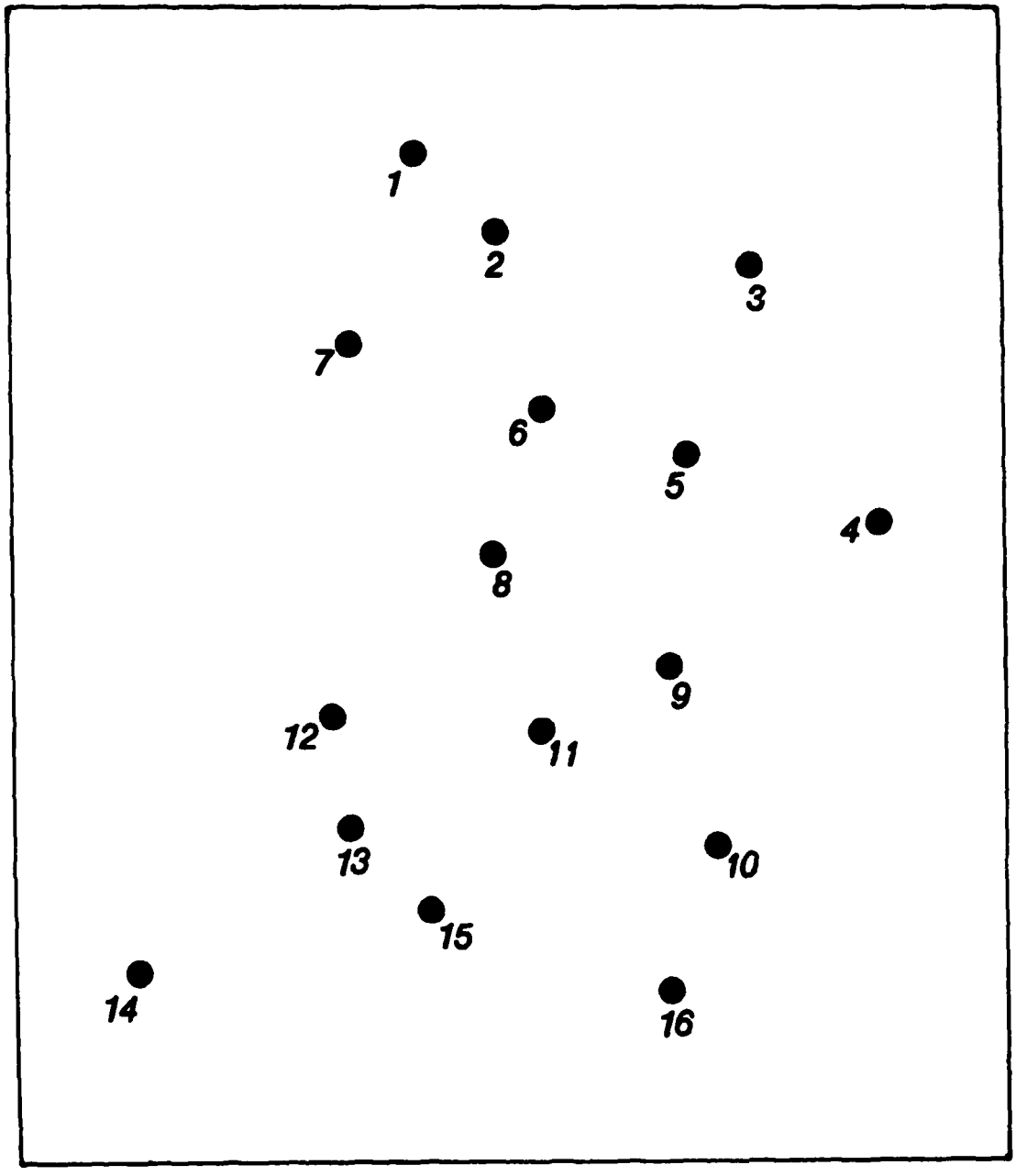

Figure 1: Sixteen Node Example

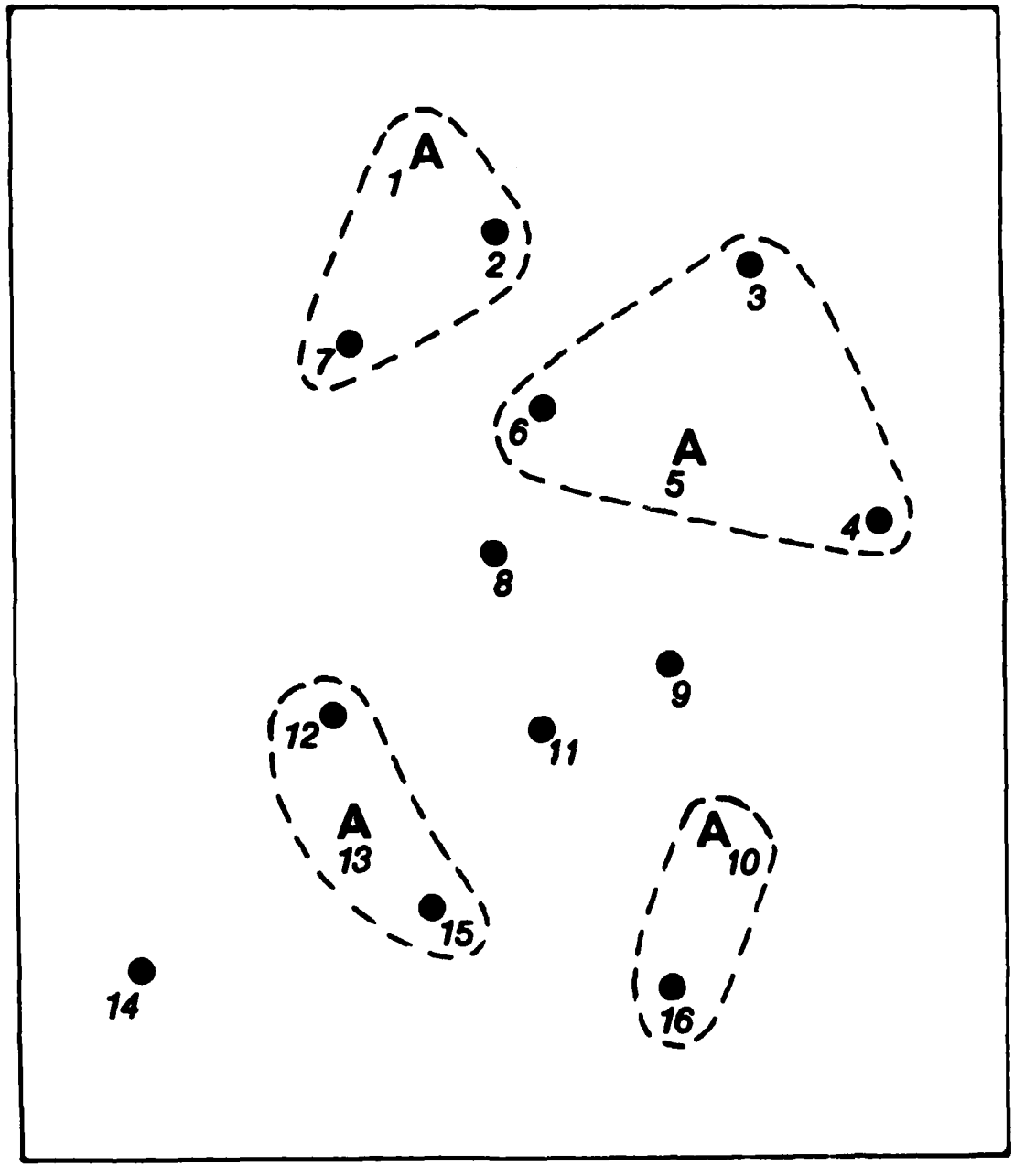

Figure 2: "Maximal Covering" Solution for ALS units, Critical Demand ($p^1 = 4$)

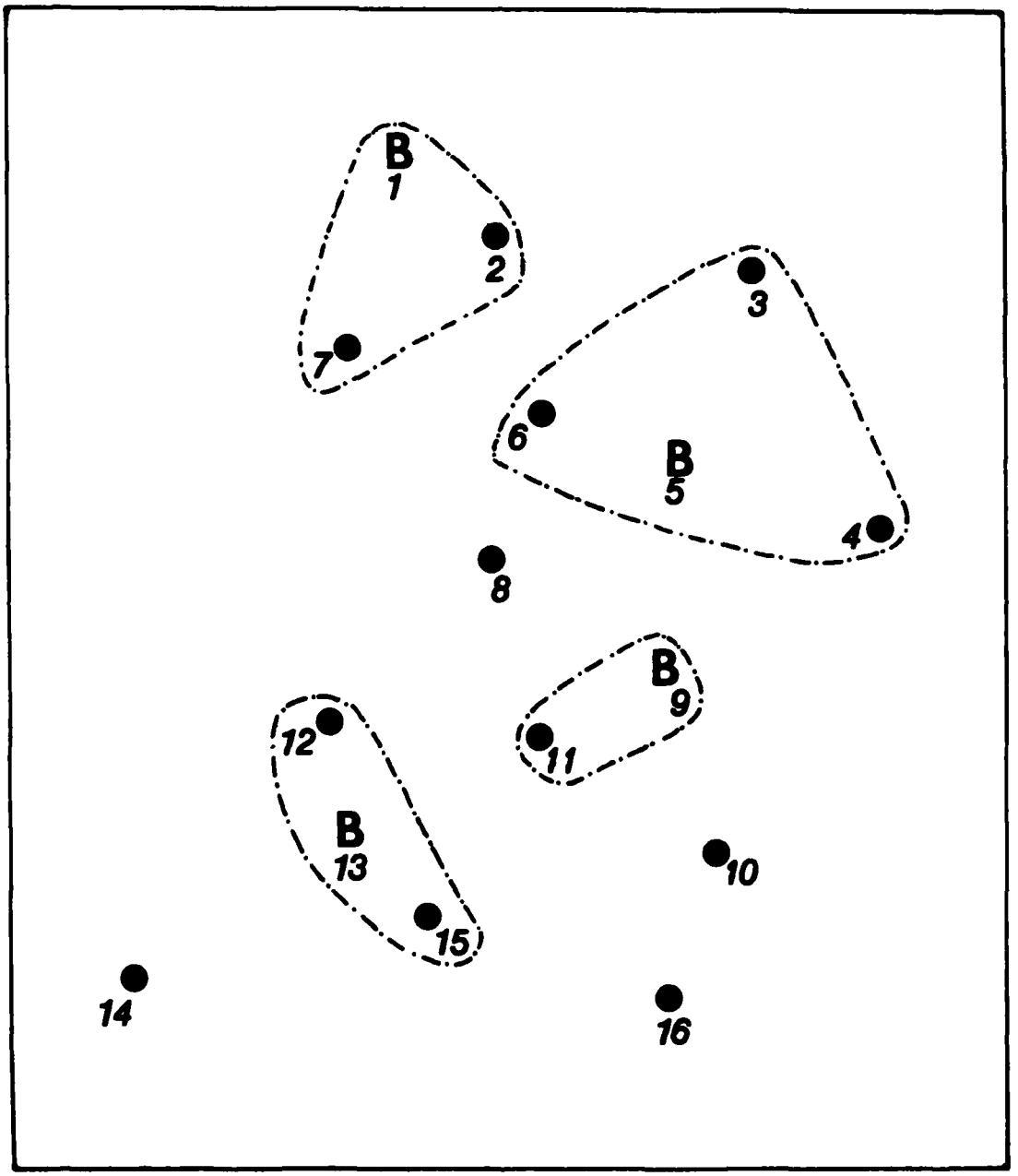

Figure 3: "Maximal Covering" Solution for BLS units, Non-critical Demand ($p^2 = 4$)

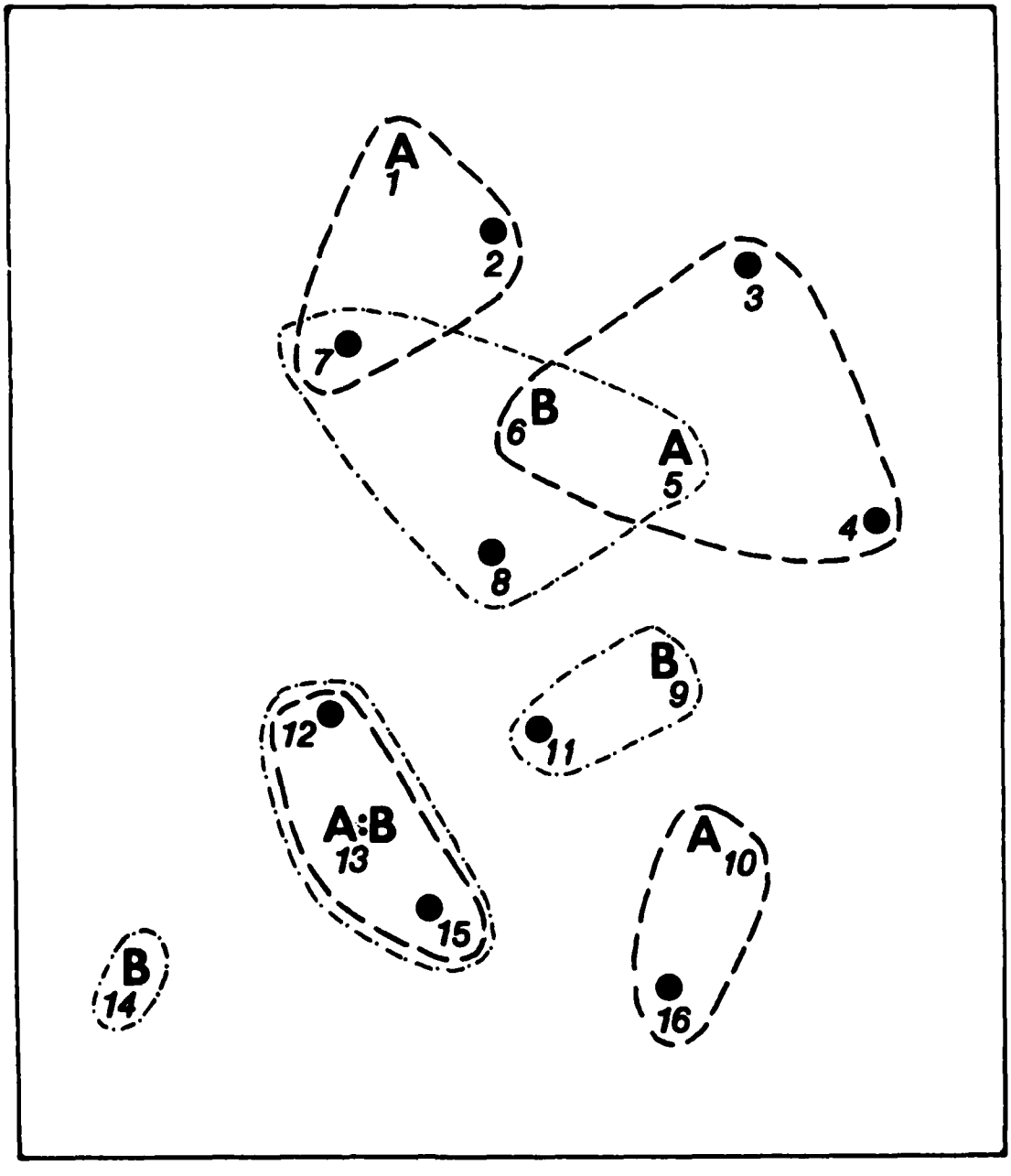

Figure 4: Multilevel Covering Solution
for ALS and BLS units
($p^1 = 4$, $p^2 = 4$)

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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EMS Hierarchy						
Goal-oriented location covering						
Multilevel location covering						

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13. ABSTRACT

Facility siting models known as location covering techniques have proven to be useful particularly for emergency medical services (EMS) planning, given the importance of ambulances responding to demand within some maximum time constraint. These models represent a set of methods which focus the health planner's attention on the access of people to health care, since they attempt to "cover" people in need of service within some specified time standard.

This research develops a technique for the locational planning of sophisticated EMS systems, characterized by multiple levels of emergency health services. Specifically, a two-tiered system with "basic life support" and "advanced life support" capabilities is modeled as a goal program.

By applying location covering techniques within a goal programming framework, this study develops a method for the siting of multilevel EMS systems so that (1) each service level maximizes coverage of its own demand population, and (2) "back-up" coordination between levels is assured. The usefulness of this goal program as a health planning tool is evidenced in the model's explicit articulation of EMS policy objectives and its ability to link system levels in terms of "goal-directed behavior." The working of this multilevel covering model is demonstrated by reference to EMS planning scenarios and related numerical examples.

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