PN - AAT - 442 41604

COOPERATIVE AGREEMENT ON HUMAN SETTLEMENTS AND NATURAL RESOURCE SYSTEMS ANALYSIS

LOCATION-ALLOCATION ALGORITHMS AS A METHOD OF LOCATING FACILITIES IN DEVELOPING COUNTRIES: EXTENSIONS TO COPE WITH IDENTIFIED POLICY CONSTRAINTS

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January 1984

1. SCOPE OF THE REVIEW.

Solutions to many development problems involve the selection of locations for activities. In the last ten years, methods and techniques for solving such problems have advanced a great deal. Any problem that involves analysis of alternative locational arrangements of activities is called here a "location-allocation problem." Although well-known and widely applied by many Operations Researchers, Management Scientists, Geographers and Regional Scientists, these methods have received little use and recognition among development administrators, planners and students of development studies.

This working paper is a brief introduction to these methods and a guide to the literature where they are described. It is set in the context of the kinds of questions that location allocation modeling can answer. Too frequently, a premature conclusion is drawn that these methods are useful for finding optimal locations but, the potential user argues, they themselves have need to answer additional questions. One of my objectives in writing this paper is to illustrate that many of these additional interesting and relevant questions that frequently occur in studying development problems can be answered by these new methods of locational analysis.

In recent years, many computer programs for solving location problems have become available and at the present time programs are becoming available for use on micro-computers. By utilizing some novel advances in the organization of data, some of these analysis systems can be used to solve quite large problems on micro computers. The availability of these codes will be discussed.

The paper concludes with a review of the use of location-allocation models in health services development and in regional settlement planning. These examples are compared with school location planning activities where these models have not been used.

2. INTRODUCTION.

Developing countries are passing through a period in which many new locations are being selected to provide basic human services to rural populations. With a smaller proportion of their populations urban than developed countries, and with transport and communication systems poorly developed and costly to use, these location decisions are critically important to the development effort. Many national governments and international agencies have recognized this and have responded with planning efforts to improve locational decisionmaking. The freedom to make future selections from a well developed spatial structure of alternatives is being fashioned by these location decisions.

Beginning in the 1960s and becoming widely applied in the 1970s, location-allocation methods are the only formal methods that have been developed to find optimal locations when many alternative locations exist. These methods evaluate alternative combinations of feasible locations and select the combination that performs best with respect

to a defined objective (see Hansen, Peeter and Thisse 1983; Hodgart 1978).

The kinds of locational decisions that have generally been made in developed countries in the past decade for public services have been different from those made in the developing countries. In the developed countries there have been many applications of location optimizing methods for "emergency services": fire, emergency medical services, police. They have also been used to study the closing of service sites such as schools. They have rarely been used to determine new service sites for basic human services. This is the location problem that is most critical in developing countries.

3. DEVELOPMENT PROBLEMS AND THE LOCATION OF ACTIVITIES.

Many problems of development can only be solved if decision-makers make 'good' location decisions. In how many cases would it not be relevant to ask the following questions of a decision to locate a given activity in a particular place?

1. Who will benefit?
2. Who will be adversely affected if it is not located in the place?
3. How will the costs of operation and the quality of the good or service be affected by the choice of location?
4. Could more people benefit if it were located elsewhere?
5. Where could it be located to 'maximize benefits'?
6. How will its location affect the performance of other activities?

These are basic questions that location allocation models are designed to address. In fact, since the best location for any one element depends on the locations of other elements in the system, these questions are excessively simplified.
Until twenty years ago, methods of analysis for such multiple location problems were primitive and unsatisfactory but, since 1965, a new set of methods, called 'location-allocation' models, have been developed.

Development Questions and Location-Allocation Models.

Any question which involves evaluating the relationship between one set of locations (demand points) and a second set of locations (supply points) is in principle a question that can be solved by location-allocation methods. Examples of such questions are:

Evaluating the Current System of Locations of a Service. Many development applications involve actions, or plans for actions, to improve the performance of a system of locations for an activity which already exists at many locations. The problem is not, therefore, a design problem of planning a new system but of improving the performance, often through incremental changes, of an existing system. The first questions often involve a critical analysis of the current

system. How well does the current system meet stated objectives? Where are the areas where stated standards are not met for geographical access to a service? Are the resources currently in use efficiently located to meet those objectives? How much improvement in meeting the stated objectives is possible for a given increase in resources? This is one set of questions which can be answered using location-allocation models.

Finding a System of Optimal Locations for a Service. A second set of questions involve the selection of locations that will best satisfy stated objectives. These objectives can be solved for single centers or many centers. Some centers can have locations that are fixed (cannot change) and the models can find solutions subject to the constraint that those locations do not change. We also distinguish between single and multiple objectives.

Single Objectives. A common optimality question is to find the locations that are optimal for meeting any one of the following single objectives.

a. To minimize aggregate (or average) travel distance; the 'p-median' problem.
b. To minimize the farthest distance; the 'min-max' problem.
c. To reach the maximum number of people within a given distance; the 'maximal covering' problem.
d. To maximize the levels of utilization of a service. In planning schools, for example, an objective is often to maximize enrollment and to minimize school dropout. In planning health centers, the objective is often to maximize utilization of the centers.

Multiple Objectives. Many location questions involve the selection of locations that meet a combination of criteria (see Bigman and ReVelle 1980). Solutions preferred by decision-makers may be inferior on any single criterion but may be sufficiently good on all significant criteria that they are considered the best solution (see Brill 1979; Schilling et al. 1982). Interest in such multiple objective decision-making has increased in the past decade and a number of location-allocation models have been constructed to solve such problems. The problems are classified into one of two types. 'Constraint based' multiple objectives occur when the decision-maker wishes to find the locations that are best with respect to one objective subject to the constraint that they meet some minimum level (the constraint) of some other objective or objectives. Examples are:

a. To minimize average distance subject to no person being more than a given distance from a center; 'maximum distance constrained, p-median problem.'
b. To reach the maximum number of people within a given distance subject to no person being more than a given distance from a center; 'maximal covering within a maximum distance constraint problem.'

The second kind of multiple objective location problem is one where each of the objectives is given a weight, or importance, and the

problem is to find the set of locations that are best with respect to the weighted objective (weight-based methods) (see ReVelle 1982). A variation of this approach is where a decision-maker's preference function is given showing the amount by which they are willing to see any amount of one objective sacrificed in order to receive a unit gain in the second objective-- this for all combinations of levels of each objective (see Hillsman 1980).

Evaluating Policies or Plans for Locating Activities. In development planning and administration, a question that often arises is whether a given policy, if implemented, would lead to desirable outcomes. Location-allocation models can often be used to simulate the application of a locational policy. Examples will be provided below.

Evaluation Changes in the Transportation System. Geographical accessibility to a service can be improved by changes in location or by changes in the transportation system or by combinations of the two. Changes in the transportation system can be evaluated by changing the inter-place distance data that is used to evaluate the accessibility of any set of locations.

4. DEVELOPMENT OF LOCATION ALLOCATION MODELS.

Historical Background

The breakthrough that enabled these methods and this literature to develop was the realization that the problem of selecting a group of locations that collectively would serve best a given location pattern of demand was a problem of selecting the best combination of places from a larger set of possible places. Could methods be developed that would systematically evaluate alternative combinations of locations and select the combination that served best the given demand? Systematic study of methods and techniques to solve such problems began in the 1960's. The earlier literature of location theory had considered many of the conceptual problems, but little progress was made in developing practical methods of finding solutions to any but the most simple of problems where assumptions about the uniform geographic distribution of demand allowed the use of geometrical methods. This literature had been developed by German geographers and economists in the 1930's. The problem that defied solution until 1963 was that the principal variable was location itself, and, as location of a service varied, so the values of other variables would change, since their values depended on the locations of the services. The problem clearly could not be expressed as an equation in which the value of one variable depended entirely on the values of a related set of variables. Social Science had made considerable progress in the previous decade by formulating its problems in the form of such equations which had a dependent and many related independent variables.

Researchers pursuing this question in the early 1960's realized

that, to be successful, a method had to be able to judge alternative location patterns and select the one that was best with respect to specified criteria. They understood that they had to develop procedures for systematically evaluating sets of locations of facilities that could identify that combination of locations that was optimal in meeting the specified criteria. Within a space of three short years, from 1962 to 1965, several individuals reached very similar conclusions and found a method for solving this problem at least for a restricted set of criteria. Success came in all cases by individuals who were able to combine their knowledge of geo-coded information systems; some basic principles of algorithmic construction; and the management and implementation of this knowledge on the computer systems which at that time were disseminating rapidly in Western Europe and North America. A literature began to develop which quickly became known as the literature of "location allocation." Many disciplines contributed to its development:

Operations Researchers, who saw in this problem area some interesting problems of optimization for which no exact algorithms could be found except for small, trivial, problems. These problems are now known as NP-complete problems and although exact algorithms do now exist for many classes of locational objectives, the area continues to hold the interest of this discipline. Operations Researchers made important advances which were quickly adopted by members of other disciplines whose interest in developing methods of solving difficult combinatorial problems was secondary to their interest in solving the substantive problems of immediate interest to them.

Geographers and Regional Scientists were the largest of the other disciplinary groups. Their main interest has been in applying these methods to evaluate the efficiency of existing systems of locations of facilities and to evaluate the efficacy of procedures for improving location patterns with respect to specified criteria. This group has recently also begun to view these methods as logical extensions of location theory.

Economics, Business Administration and Marketing is a third discipline area that has contributed to this literature. Economists saw this as an extension of the methods of cost-benefit analysis for the locational aspect of alternative decisions. Marketing specialists and land economists saw in these methods new and more relevant ways to evaluate the development potential of specific sites. They have often used the methods to find optimal locations for given activities whose success and economic potential depends on providing goods or services to people at dispersed locations.

A fourth group of disciplines whose contribution to this literature is more recent is the group of professions whose interest is in particular service delivery systems: Hospital Administrators, Education Administrators, Social Workers, Public Administration specialists, Bankers, Managers of emergency response systems. The list is much longer than this.

Despite this wide range of applications and the variety of disciplines involved, both applied and basic, who find this literature interesting, the applications to problems in developing countries have been quite few. The barriers to adoption are several. The materials are still rarely a part of the curriculum of Universities and Colleges in developing countries. The availability of the computer hardware and software needed for many of the applications is limited. The geographical information systems are less well-known and developed in most developing countries. None of these barriers is insurmountable if it is clear that the benefits of adopting these methods are great.

Importance of Hakimi's Theorem

In the development of location allocation methods, The problem was simplified by the discovery of a mathematical theorem by Hakimi in 1964 and extended in 1967 by Levy showing that, if the objective was to find locations that minimized the travel distance between the demand locations and their closest supply location, then, providing people or goods travelled on a network (roads, railways, footpaths, etc.), the best locations would always be at the nodes of the network. To find the best location pattern to meet this objective required, therefore, the examination of alternative nodes on the network rather than the infinity of locations existing in the area as a whole. These discoveries led to the development of "discrete-space location-allocation models" which now dominate the literature (see Hansen, Peeters and Thisse 1983). It was soon discovered that there were several quite different methods for solving these problems.

Solving for Different Objectives with One Algorithm.

Until about seven years ago, it was common for analysts to view each objective as requiring a particular algorithm for its solution. The pioneering work of Church and ReVelle (1976); ReVelle and Church (1977) and of Hillsman (1980, 1983), however, has shown that many different objectives can be shown to be special cases of the p-median problem and solved by any of the methods that are known to solve that problem (Maranzana 1964; Erlenkotter 1978; Teitz and Bart 1968; Kuehn and Hamburger 1963). Although knowledge of this development does not appear to have diffused very widely among users of location allocation models, it does promise to qualitatively change many areas of application. If the analyst is free to solve for different objectives using the same algorithm, one can expect more frequent comparisons of the performance of given location patterns or plans for new services against a wider range of objectives. Such comparisons will enable decision makers to make better judgments about their original choice of objectives. Fisher and Rushton (1979) argue that decision makers usually need this information in order to know whether their choice of objectives was correct. The argument is that decision makers are often acting "idealistically" when they define standards of expected service for some activity that they are charged to provide. "No child should have to walk more than five kilometers to a middle school," is

typical of a standard to which we refer. In making the standard, however, the decision maker usually has no knowledge of what it will cost to meet the standard. Yet, in real life, don't we hesitate to set a standard for our own behavior, if we don't know the cost of meeting it?

Calculating the Cost of Meeting Locational Standards.

This recent development in location-allocation modeling thus allows the analyst to provide the decision maker with information about the performance of location plans with respect to many alternative objectives and allows the computation of new location plans that are optimal with respect to a single or weighted combination of several objectives. This information is usually displayed in "solution spaces" that are computed by the location allocation analyst for the decision maker. After examining these spaces which, in general, have typical shaped curves on the graphs in which they are displayed, decision makers can reformulate their objectives and the analyst can determine the locations that meet the revised objectives. The p-median curve, for example, shows how many locations are needed to serve the population of an area when these locations have been selected to minimize the average distance of all people to their closest center. Although the curve will always be downward sloping to the right and always be convex with respect to the origin, its precise shape will depend on the distribution of demand and the transport structure of the particular study area. A decision maker who knows the cost of establishing a new center can compare the reduction in average distance (the benefit of the additional location) with the cost of establishing and operating the new locations to establish the cost/benefit ratio. Because the p-median curve is concave, the diminishing of the reduction in average distance with each increase in the number of centers represents diminishing returns to scale as increasing decentralization takes place. When utilization of a center is known to decline with distance (as with many health centers, for example), a function can be computed that will show the expected increase in aggregate utilization that would occur with each increase in the number of centers (ReVelle and Church 1977).

Current Research Areas in Location-Allocation Modeling.

There are several recent important developments in location-allocation methods. One line of enquiry proposes to incorporate more "realistic" geographical assignments of people to facilities where differences exist in the characteristics of facilities that are known to influence the locational choices of people (see Hodgson 1978; Beaumont 1980; Leonardi 1982). These developments are still presumably in their infancy since it is widely recognized that even though a person's spatial choice of a service location will often depend on its characteristics compared with the service at other locations, the characteristics of any facility will often depend on the number of people who choose to use it (see

Goodchild 1978; Rushton 1971). Though methods for forecasting the spatial choices of people given their personal characteristics and the relevant characteristics of the places between which they are choosing are well-developed (see Horowitz 1981), use of these methods does imply that the characteristics of the opportunities between which people choose are known and are stable. There is a long tradition of using thse methods (spatial-interaction models) to forecast expected use levels of service or business facilities with hypothetical characteristics at alternative locations. Viewed in this way the problem is one of generalizing these models to accommodate a larger set of combinations of alternative locations and a greater variation in the activity characteristics at the locations. Further progress in solving this problem can be expected in the future.

In a second line of enquiry, investigators are determining whether errors in distance measurements occur when a dispersed population is assumed to live at discrete locations (often at nodes on a network). How sensitive are the solutions to optimal location problems to the "degree of spatial aggregation" of the data? If small data units (for example, traffic zones) exist in one part of a study area and larger data units in another, does this fact introduce a bias in the measurement of geographical accessibility such that the solutions to optimal location problems are more or less likely to include places in the area of large data units? (See Goodchild 1979) Does the spatial aggregation of demand data lead to an over or an under-estimation of distance separation in the results from a location-allocation model (see Hillsman and Rhoda 1979; Casillas 1983)? Can methods be devised to reduce this error by spatially disaggregating data (see Tobler 1981; Park 1983)?

A third set of studies is investigating the predictability of distances between places. The cost of assembling accurate geographical information systems containing this data from empirical observation is great and given that distances actually experienced by people will often reflect local conditions prevailing at the time of travel (weather conditions, the time of day etc.), there is reason to consider the generation of travel distances as computed from a function of the expected values of the locational coordinates of the places, relevant characteristics of the transportation system, and of the traveller (see Nordbeck 1963; Love and Morris 1972, 1979; Kolesar 1979; Timbers 1967).

5. IMPLEMENTATION OF THE PRINCIPLES.

Data Requirements.

There are two sets of data that are essential to most applications of location allocation models. Together, when coded and organized as described below they comprise the basic geographical information system. Data is required that describes the locations, place characteristics and distances with respect to other places in the study area. It will often contain information on places outside the study area and the links to them from the study area. This is especially important when study areas are defined as political or administrative areas the boundaries of which are not generally recognized by the local population when using urban functions. A typical data set will consist of two parts.

Place characteristics data. This includes name of the place, identification code of the place, relationship of the place to the study area (inside or outside the study area); locational coordinates of the place, general socio-economic data on the place such as population; particular social-economic data on the place relevant to the proposed application. For example, if a study of access to health services is planned, then data that describes, or that can be used to estimate, the demand for health services would be included as also might data on the presence or absence of a hospital or health center in each place.

Inter-place distance or Cost data. This is generally organized as a table of distances between each place and every other place. It can be coded by hand after making measurements from a map of all distances but, more commonly, it is produced by a computer analysis. Two methods are used:

a) Compute distances from the locational coordinates of the places. These can be computed as distances along the axes of the coordinates when they are known as a "city-block" or a "manhattan" distance metric. They can also be computed as straight line distances when they are known as "euclidean distances", or "crows flight" distances. The advantage of this approach is its simplicity, small information needs and small susceptibility to error. It is a robust method in which, though the distances computed are only estimates of the true distances, they often will have as good a correspondence with the distances people actually encounter as the distances one might compute based on inaccurate maps or maps which, though accurate, may have been improperly coded. For planning purposes, these distances will often more closely relate to distances that can become true as the route structure develops to meet the spatial linkage needs of a population. For a discussion of methods of estimating true distances from distances computed from coordinates, see Kolesar

1981 and Love and Morris 1980.

b) Compute distances from a coding of a base map. These are "shortest-path" distances and can be computed by computer using any one of a variety of algorithms that are widely available. A "tree searching algorithm" coded by Ostresh (see Rushton, Goodchild and Ostresh 1973) is simple, runs on small computers even for large problems (3,000 nodes, for example) can be used to find the shortest distance by a combination of route modes in which travel speeds or cost differ by type of route and has a code that is published. An excellent technical description of this algorithm is found in Larson and Odoni (1981, pp. 364-371).

Analysis Objectives.

The information described above is a geographical information system that is common to most of the specific objectives used in any particular application. Each application will have its own objectives and these must be stated so that the appropriate algorithm or data editing feature can be selected. There are three broad objectives which many analyses follow.

a) Evaluate the levels of geographical accessibility of the current system. This analysis gives the current norms. If there are standards of access, this analysis can be used to compare current norms with the standards.

b) Identify and prioritize further locations which, if added to the existing service locations, will bring the system closest to the stated standards.

c) Evaluate recent location decisions for the service to determine whether they were effective in relation to those identified in b) in bringing the system into conformance with the standard.

Choice of Objective Function. Many of the analysis objectives will begin with the objective of computing "solution spaces" for the study region for the "demand" pattern that needs to be served (see Fisher and Rushton 1979).

Specification of Information Outcomes. This is where the decision makers, having identified their objectives, should decide what information they would like to have about the systems they analyze. Location allocation analyses can be used not only to select locations that optimize given criteria, but also can be used to measure many important aspects of current, planned or computed locational systems. Information that is often needed is:

a) Identify the settlements and areas that will use the service at any place. These "trade-off" characteristics give vital information for service system planning. What are their sizes,

their population characteristics, the local geographical accessibility conditions?

b) What is the distribution of distances that people will have to travel in the "new system" as compared with the "old"?

c) How many people will travel more and how many less distance in the two systems? How many people are adversely affected and by how much?

d) How many people would be expected to use the same service center that they had previously used?

e) If one is interested in different groups of people, (for example, young and old, high caste and low caste, rich and poor), how are these groups affected by the analysis plans?

f) How many service sites would be needed to provide the same level of geographical accessibility as the current system? How many of the current service center locations would be retained in such an optimal system?

g) Is there a recognizable regional shift in resource allocation when the optimal location pattern of resources is compared with the present?

h) What is the increase in geographical accessibility (however defined in the specific case), of the last center added to the optimal set (the marginal center)? How does this value change as the number in optimal set changes?

Selection of an Appropriate Location- Allocation Analysis System.

Based on the above discussion, the choice of an appropriate analysis system should be made. Criteria for such a choice include the size of the problem, the degree of detail in the geographical information system, the access of the analyst to computing systems of given characteristics, the particular types of questions answered and the types of information-outcomes desired. The resources available for the analysis is also a factor to be considered. One of the first decisions is whether the analyst will view the problem as a "discrete-space" or "continuous-space" problem. If the latter (see Tornquist 1971; Beaumont 1981), solutions will be found anywhere in the region and, although constraints can be added to constrain current locations to remain unchanged and other locations can be arbitrarily added and then locations fixed (if desired by the analyst), the remaining locations are generally free to be located by the algorithm wherever in the region is computed to be best to meet the specified locational objective. If such a decision is made, economy is achieved in data input (locational coordinates, rather than a distance matrix is the basic geographical information system), and economy is achieved in the size of the immediate access computer memory (RAM) required

(since n x 2 locational coordinates rather than the normally required n x n distances are stored). Achieving these economies is thus often the reason for choice of these algorithms and analysis systems. Examples of these systems are TORN and LAP (see Ch.5 and Ch.6 in Rushton, Goodchild and Ostresh 1973); see also programs LOC1 and LOCM in Robinson (1983a pp.52-56). Moore (1982, pp.220-222) gives a detailed description of the sequence of steps he followed from acquisition of source materials, data coding and preparation prior to location-allocation analyses, and preparation of results to supply information on many of the questions described above.

The disadvantages of selecting a continuous space algorithm are that at the present time these published algorithms cannot solve the range of locational objectives ("objective functions") that can be solved with discrete space algorithms. True distances or other measures of distance separation of interest to the analyst, (for example, time or cost "distances"), cannot be used. Using these programs the analyst does not have the flexibility to choose alternative solution procedures. In addition, the designation of particular places as "eligible" locations for the activity is not usually possible using these programs. If the analyst decides to designate locations as eligible or ineligible for the activity, wishes to input rather than compute measures of distances between places and wishes to compute solutions for alternative locational objectives, then discrete-space algorithms should be used.

A second key decision is whether to use a heuristic or an exact algorithm. Computer codes for heuristic algorithms are widely available whereas, especially in developing countries, computer codes for exact solutions are frequently not available. In any case, the accuracy of some heuristic algorithms, particularly those with location substitution elements, is now known to be extremely good for a variety of objectives (see Rosing et al. 1981). Eaton et al. 1981 had used a greedy adding and substitution heuristic (see Church and ReVelle 1974) to determine village health centers in Columbia. They repeated their analyses using a linear programming code MPSX and found that in all four cases examined identical solutions were found (see Eaton et al. 1981, p.344 and p. 353). It appears, therefore, that heuristic algorithms are adequate where cost, size of problem, or computer hardware and software availability preclude solving problems by exact methods.

Use of Non-Computerized Location-Allocation Methods. In an attempt to hasten the adoption of the concepts of location-allocation analysis even at the risk of implementing approximations of the solutions one wishes to find, methods have been developed to apply these concepts using graphical, analogue procedure, These are explained in detail in Fisher and Rushton 1977; Roy and Patil 1976; Fisher and Banerji 1975. These methods use covering circle templates which can be moved as overlays on a base map on which relevant data is shown on the transportation system, and on the population and current service characteristics of the area. An alternative procedure involves the progressive subdivision of the region based on bisection of the lines joining places currently offering the service in question. Searches of these "uncovered" or "interstitial" areas allows the analyst to

focus on their characteristics, to compare them and to rank them by priority according to the criteria of which locational change, if made to the system, would most improve the performance of the system. In introducing such "rules for prioritizing location investments," the analyst is often duplicating rules that are followed in conventional heuristic optimizing algorithms. Consequently, even though the best single-locational improvement may not be selected by this rough, "manual" procedure, because the system is being improved in a significant way by each incremental change, it can be argued that the ultimate result of a repetitive application of such a procedure will lead to a system of greater relative efficiency than one which has evolved through the normal process of accepting or rejecting particular proposals for change emanating from the places themselves.

Availability of Computerized Location-Allocation Systems. No published inventory of existing analysis systems exists. One system that can provide much of the information described above is Hillsman, (1978). A second system, designed for micro computers but able at this time to analyze only small location-allocation problems is Robinson (1983). Rushton, Goodchild and Ostresh (1973), contains a collection of computer programs for both discrete and continuous location-allocation problems using a variety of heuristic algorithms. All these programs are in the public domain and program documentation and source codes (either printed or in machine readable forms) are available at cost.

Barriers to Implementation.

I will define implementation within the context of an area that already has the basic information. The cost of gathering that information where it is not immediately available will differ greatly from one area to another. I will not, however, presume that distances between all places are known. I assume, instead, that a map of the study area exists of sufficient quality and scale to allow all places to be identified, types of route connections between places to be coded and that distances can be measured along any defined route link between two directly connected places. I will assume as a typical area an area of perhaps a million people who can be classified as belonging to any one of five hundred settlements. Many practical applications are covered by this example although the size of the study area assumed is not a limit to applications that use mini or large-frame computers. The size limit of applications of micro-computers are not yet established and great differences in these limits can exist between different computer codes.

Assembling the Information System. There is no doubt that assembling an accurate geo-coded information system represents the greatest barrier to application of location allocation models. This represents a high fixed cost (see Moore 1982, pp. 210-211). It is also a difficult professional task to ensure that the information in the system is accurate. Fisher (1979, p.36), reported that "A few errors in the preparation of road distance inputs to a recent Indonesian application, for example, led to a two-month delay in producing meaningful ALLOC results." Some progress has been made in developing algorithms which will identify probable errors in a shortest path matrix of distances (see Ginsburgh and Hansen 1974). These methods are often related to the methods of predicting distances between places (see Love and Morris 1979).

Access to Computer Hardware and Software. A second barrier is availability of a suitable computer, access to software and persons with suitable professional training. Professional planning schools and Departments of Geography and Economics in developing countries rarely are able to provide technical training in such methods and analysis systems. The few people with professional training in computer science are generally too unfamiliar with the substance of the problem and the techniques to be able to complete analyses unaided. Some of the software available has not been designed to solve development problems of the size commonly encountered. Fisher (1979, p.36) observed that "Problems including more than 1,000 settlement or junction nodes among which several hundred possible centers must be examined are not at all unusual in developing nations. Last year in Indonesia, for example, locations for more than 50 new schools in each of several provinces had to be chosen. Manual location alllocation methods had to be relied upon in part because available computer algorithms could not manage problems of this size."

Instruction in Location-Allocation Methods. A number of workshops have been organized in developing countries to assist in the dissemination of these materials. Dr. McNulty and I have participated in a three week workshop at The Institute for Development Studies, The University of Mysore, India on "Location of Public Services", August 1978. We also were resource persons at a four day seminar on location allocation methods at The National Technical University, Athens, Greece in March, 1981; and in a three day seminar in January 1981 at The Indian Institute of Management, Bangalore, India. I have given a one week workshop on the subject at The University of Madras (January, 1980). A group at The Indian Institute of Management, Bangalore under the direction of V.K. Tewari have developed new computer programs and tested them on several rural service planning problems. At The Indian Institute of Management, Ahmedabad an active group of Management Scientists is similarly experienced. They have developed special graphical output programs to assist decision-makers involved in the process of making locational decisions. They include S.C. Bhatanagar and N. Patil. V.C. Robinson from Hunter College, City University of New York has given several workshops in developing countries using his recently developed Urban Data Management System. At The University of Texas, Dr. David Eaton organized a month long workshop on the

application of location analysis to problems of deployment of health resources for health planners from Columbia (see Eaton, Church and ReVelle 1977).

6. AN ILLUSTRATION

In this section an illustration will be described showing a selection of eleven optimal locations in a region of Nigeria. The purpose of the illustration is to show the steps that had to be taken for one typical analysis in a series of analyses conducted by a team of geographers and development specialists at The University of Iowa and The University of Ibadan, Nigeria (see acknowledgements) The illustration was completed within a period of three days in the summer of 1983. For the sake of realism, as well as to communicate the contingency of one stage of analysis with that of the next, the illustration will be described in terms of the stages of the analysis day by day.

Background.

A collaborative agreement between the University of Iowa, U.S.A., The University of Ibadan, Nigeria, and the Indian Institute of Management, Bangalore, India, had been arranged in 1980. The terms were that a series of locational analyses of rural service delivery systems would be completed in Nigeria and India using comparable data and analysis systems. (Support for the work was provided by The National Science Foundation, U.S.A. and by the respective educational institutions of the investigators.) A locational analysis system developed earlier in Iowa was implemented and then substantially modified at the IIMB by the Indian research team under the direction of Professor V.K.Tewari.

A similar attempt in Ibadan was not successful due to several disruptions of computer services there. In order to complete the Nigerian analyses, Dr. Bola Ayeni from The University of Ibadan arranged to visit The University of Iowa in July 1983, to complete the Nigerian analyses there. He brought coding tablets showing the population totals and the locations of the 675 places in his study region, which was a rural region to the southwest of Ibadan. He also brought information on the location of health services such as clinics, maternity units and general hospitals. He had also determined the temporal sequence in which these services had been added to the region during the past three years. Upon arrival in Iowa he was met by Professors Rushton and McNulty from the Department of Geography, who served as technical advisers during the next three days. Mr. Soo Byong Park, a research assistant to Dr. Rushton was technical specialist in charge of the analyses. He is a specialist in locational analysis within the graduate program of The Department of Geography. The computer system used during this period was an IBM

370.

Purpose of This Analysis

This example begins with the analyst having defined a study area, collected basic data on locations of demand for a rural service, estimated the demand at each location, and collected data on the current locations and organization of the service outlets. The example describes the steps that were taken by the technical analyst from the data stage to the results of an analysis which determine the optimal locations of an activity and compare the relative performance of these locations with that of an externally defined set. Often, this set will be the existing locations of a service, so that the effect of the comparison is to assess the current locational efficiency and effectiveness of the existing service delivery system.

Format of the Illustration.

This illustration shows, alternately, the input that Mr. Park submitted, and the output that he received for each step of the analysis. Since the data set is large and the output is also large, selections were made by editing the input submisssion and the output received. Many of the inputs are explained in lower case lettering, in most cases, in the boxes on the figures. The editing was designed by Dr. Rushton and Mr. Park to reveal all the key functional steps and decisions made by the analyst in conducting similar analyses.

Analysis System

The analysis system used is a modified version of the system developed by Hillsman. (see Hillsman. 1980). The modifications were designed by Professors Rushton and McNulty and were programmed and added to Hillsman's original code by S. Park. The principal changes made are those that enable a detailed comparison of the original input locations with those computed by the algorithm for any of the analyses executed by the program. This feature was not available in the program as originally published by Hillsman. Compatibility with the published software documentation was maintained in that the changes affect the output characteristics and are therefore changes that are intrinsic to the code. The changes, with one exception, do not affect the input characteristics and therefore the program can be used with Hillsman's documentation. The program is known as ALLOC 6B and is available from The Department of Geography at The University of Iowa.

Day One: Creating the Distance Matrix.

The first step was to create the distance data between all the places. In the ALLOC system (see Hillsman 1980), this can be achieved by computing shortest paths along route networks between all places (see Ostresh 1973), or by computing distances from the cartesian coordinates of the places. This is the approach followed in this illustration. The program DISTANCE (see Hillsman 1980, p.13) was used (Figure 1). Although 71 lines of code are omitted in this figure, the illustration shows the user loading a short FORTRAN program and reserving memory in the dimension statement for four vectors of values corresponding with the x,y, coordinates, the identification codes and the distance values. Memory needs are, therefore, 4n + 20 where n is the number of places in the study area.

The input data for this analysis, explained in the boxes in Figure 2, show the user reserving a disc drive and naming a disc file to store the distances after they have been created. The control codes show the number of places involved in the analysis and the type of distances to be computed (straight line or city block types of distances). The format of the data and the data itself is added to the input file. Several lines of data are shown in Figure 2.

The output from the program DISTANCE begins by confirming that the input specifications were correctly interpreted. One of the input controls specified that the input data should be shown, so it is here. The listing of the distance matrix, if requested at input time, starts by showing the ID of the place from which distances have been computed (10001 in Figure 3). This is followed by the computed distances to all the other places, including itself, in the order that the places appeared in the input data. Examination of the second set of distances, shown on the bottom of Figure 3, for example, shows that the distance from place 10002 to 10001 is 117, that its distance to itself is 0 and that its distance to 10004 is 68. (We know this because 10004 is the fourth set of coordinates in the input coordinates). For this type of data output we say that the ID connected with any distance is implicit because it is not explicitly shown but, rather, is known because of its relationship to the known structure of the input data; in this case, to the ID's connected to the location coordinates file.

Creating Distance Strings. The second step in the analysis is the creation of distance strings from the distance matrix. The purpose of this step is to reduce the number of distances that will eventually be used in the analyses and to provide a data structure that will allow efficient computation of the steps in the analyses that follow. Both purposes have the effect of allowing large problems to be solved by small computers using small amounts of computing time. A more detailed description of these purposes and how distance strings accomplish the savings in computer memory requirements and in computation time is provided elsewhere (Hillsman 1980, pp. 81-92). A description of the distance strings is provided below in the description of the output of the program, UNRAVEL, that creates them.

As Figure 4 indicates, UNRAVEL is a small FORTRAN program that

takes the output from the previous program, DISTANCE, and rearranges the data into a form more suitable for locational analyses. The first half of Figure 4 describes the dimensioning requirements of UNRAVEL.

Input controls for program UNRAVEL are shown in Figure 5. The first item of information required is the location and description of the distance matrix. Notice that the distances could, at this point, have come from any source, provided they have been organized in a form similar to that produced by program DISTANCE as described earlier. The second item identifies the disc where the results of this analysis are to be stored and assigns a name to this data file. The third item describes key aspects of the distance matrix and, in the second data piece of this line, it defines the largest distance (in this case 750 units), which is to be saved in the results of UNRAVEL. In other words, all distances larger than a given value will be discarded. This option is based on the knowledge that, for most locational analyses, it is never necessary to know the distance from far away places to one another. If the analysis is of hospitals, for example, everyone will have an hospital within some given distance. If this distance can be estimated, then all distances larger than this can usually be discarded without affecting the results of the desired analyses. These distances are simply unnecessary and discarding them saves the amount of memory locations that need to be reserved for the analyses and allows results to be computed in a shorter computation time. The fourth item of information in Figure 5 is the format, which describes how the information in the distance matrix is organized.

In Figure 6, the output showing the distance strings is described. The first six lines consist of a confirmation that the input commands were correctly received. The data is organized to be analyzed sequentially in two long data strings with the analysis programs organized so that they can skip over data that are known at any particular stage of an analysis to be redundant. One file is the index file and is essentially a key that is used to interpret the meaning of the distances in the distance file, which is the second of these two files.

The first data line in this example (Figure 6), shows that the first element identifies the index file with a consecutive series starting with one. The index file here shows that it is the first of this index sequence; that it describes distances from place ID 10001 to all other nodes within 750 distance units of itself; that these distances start at the first position in the distance string and end at the 584th position. Before examining the distances themselves below this index file, examine the second record of the index file in the lower half of Figure 6. It shows that there are 558 places within 750 distance units of the ID with which it begins (10002). These distances can be found beginning with the 585th element in the distance string and ending with the one in the 1142nd. position. The last data set on this figure is the description of the third record in the index file.

Returning to the middle of Figure 6, the distance string itself is shown. The three boxes above the distance data relate the distances below to the key in the corresponding part of the index file. Thus, from ID 10001, the closest place is the first place in the distance string (which, in this case is itself) and the distance

between these "places" is zero. The second closest place to 10001 is the third place in the distance matrix. The distance from it is 13 units. As indicated in the index file, there are 584 distances within 750 units of place 10001, so there are 584 corresponding pairs of distances and place identifiers all arranged in ascending order of distance from the closest to the farthest from place 10001.

This data structure is discussed in more detail in Hillsman (1980, pp.85-90). It is the key to the solution of large location analysis problems within small computing times. However, note, in this example how program UNRAVEL has been designed to automatically keep track of the data it reorganizes. Consequently, data errors will not occur if the analyses are carefully conducted.

Day Two: Editing the Distance Strings.

The analyses continued on day two with further editing of the distance strings. This phase of the analysis is, in fact, optional in that results of subsequent analyses could have been computed with the use of the output of program UNRAVEL. The decision to perform this phase, which uses program RETRENCH, is a decision which is made in the interest of streamlining the analyses which follow so that they will use less compute time and require less computer memory core.

The philosophy behind the use of RETRENCH is described in Hillsman (1980, pp.137-41). The object of the retrench phase is to eliminate distance data from the UNRAVEL distance strings that can be shown to be unnecessary for any of the locational analyses that will later be required. If, for example, it is known that a certain place will never be a candidate for a service site (although its population will need to receive the service), then the distances from that place to all other places are not needed since they already exist in the distance strings of the other places that might possibly serve them. Such places that require service but which will never, themselves, be service sites, are known as ineligible places. The remaining places are known as candidate places. In Figure 7 the beginning section of the program RETRENCH is shown. Note how, in addition to the distance strings produced by UNRAVEL, this program also uses the "population file." In the RETRENCH "philosophy" it is argued that although candidate places may often be identified arbitrarily by the investigator, at other times the status of being a candidate will be defined in terms of whether the place meets or does not meet a stated level in some variable. Because the analyst can use any variable that can be quantified, this output uses the neutral term "weight" in describing the variable. In this illustration, "population" is used as the "weight."

The first part of Figure 8 shows that four disc areas and related file names must be identified for the purposes indicated in the Figure. The control information (center part of Figure 8) shows that a new and smaller distance limit can be defined in RETRENCH (400 in this example). In this particular sample analysis, the "population" value was used to define "candidacy." All places with more than 300 people were defined as candidate places. In the middle of the data line controlling RETRENCH, the number 127 is interpreted

to mean that 127 places here will have their candidacy status defined arbitrarily (see below).

The string of ones toward the bottom of Figure 8 show that the distinction between a place being inside or outside the study region can be recorded so that subsequent analyses can give results describing the geographical accessibility characteristics of people inside or outside the study region.

The output of RETRENCH is compatible with that from UNRAVEL, described earlier. In the case of RETRENCH it is obviously important that a thorough check be made to determine that all edits that were intended by the analyst were correctly executed. If a place was inadvertently declared ineligible (by not declaring it to be a candidate), then all subsequent analyses would show it to be outside the optimal set. It would not be clear to the analyst that the reason might be the misspecification of its eligibility status at this earlier stage of the analysis. Where a place is not a candidate, its distance string is removed and all subsequent index file elements will have their values adjusted to reflect this paring of the distance string length. This happened with the third record in the index file in the example in Figure 9.

Day Three: First Locational Analysis Results.

The first analysis on day three was a test analysis to find the eleven places which together would minimize the average distance of the population to the closest of the eleven places and to compare the results with the present eleven state administrative centers in the region.

The program used was ALLOC 6B, which executes the optimizing phase exactly as designed and programmed by Hillsman (1980), but which performs more computations on the results of the analysis than are done by the ALLOC 6 provided by Hillsman.

The key control information is shown in the middle of Figure 10. This information is telling the program the sources of the data sets and the parameters of the earlier analyses. The ALLOC 6 software is designed to adjust to the different combinations of source data. This particular analysis operated on the distance string data produced by RETRENCH (Figure 6). It is also possible, however, to operate ALLOC6 or ALLOC6B directly on the data produced by UNRAVEL. The input control data, which starts with the number 11 (near bottom of Figure 10), specifies that in this particular analysis, eleven places are to be selected and that the algorithm to be employed is the heuristic location-allocation algorithm developed by Teitz and Bart (1968). Details of other options are described by Hillsman (1980, pp.113-117).

The final set of data on Figure 10 identifies the place ID's of the eleven places that are to be compared with the eleven places selected by the algorithm. These places must, of course, be candidate places. If they are not, the code will identify any places not candidates and will print an error message and will terminate.

A slightly edited (to reduce output size) description of the output is shown on Figures 11 through 16. Much of this output is self explanatory. Figure 11 shows the confirmation of the input data. It

is useful for trouble shooting when an analysis is not executing due to an incorrect specification of input data. The item describing the division of weights by 10 (middle of Figure 11) is a feature that allows output to appear in units desired. Populations times distance, for example, when distances are measured in tenths of a kilometer, can lead to large numbers that are cumbersome to manipulate in the output. The program is counting the distances in the distance string and recording its length (202,828 in this case). At the bottom of Figure 11, a list is provided of the places in the study area by name, ID, and population.

The output shown in Figure 12 is the first part of the analysis. It consists of an analysis of the eleven places (as shown on the bottom of Figure 10), that were to be evaluated before the optimal locations were determined. The first line of the table at the top of this figure is a description of the status of the first of these eleven places. Okenla, ID 40069, has a population (which is the weight in this example) of 130. This is shown as 13 in this output because all weights were divided by 10 in this analysis (see middle of Figure 11). The next value in this line, reading from left to right, shows that the population of all the places that are closer to Okenla than to any of the other ten places, is 85,040. The total person distance is 1,134,790 kilometers, if every one of these people were to make one visit to Okenla. The final value on this line, 39,286, shows that these people would have to travel an additional 392,860 kilometers if Okenla were to stop offering the service and they then had to travel to the second closest of the eleven places. The phrase "cost if dropped" is used to describe this extra distance cost that would be incurred if the people now receiving service from a place, received it from the next best alternative. It is a measure of the importance of a place in any rural delivery system. The larger the "cost if dropped," the more important is the place in the delivery system. "Drop" algorithms in the location-allocation literature use this value to eliminate, from a set of places, the place with the smallest "cost if dropped." This information is given for each of the eleven places identified as "the starting solution." (see bottom of Figure 10).

The information at the center of Figure 12 is summary information for the eleven places described above. The term "allocated places" refers to the option that places outside the study area can be a part of the data set but ignored in the computation of the summary statistics.

The information in the lower half of Figure 12 identifies, for each of the 675 places in the study, the closest center and its distance from them. Finally, in the bottom section of the Figure, the service areas are described sequentially. For each of the eleven centers, the places that are closer to them than to any alternate center are identified by their ID's. Their populations and their distances from the center are also given. These two tables, which often are quite lengthy, contain the same information. The difference is that in the "list of nodes," the center relationship of any place is easily found because the order of the table is by place ID. In the second table, the service center of any center is easily found because the places have been grouped together by their association with a

center.

Figure 13 begins with a re-statement of summary statistics, but then describes some key statistics about the search for a better set of eleven centers by, in this illustration, the Teitz and Bart heuristic algorithm. It shows how center 10032 is replaced by center 10001 and how the total cost (in this case the total weighted distance separation from all places to their closest center), decreases from 809110 (see top line of Figure 13) to 808426. The line notes that this is a net change of 684 and expresses this as a percent of the total distance separation as a measure of its significance.

The bottom half of Figure 13 repeats the format of the table described above and found on Figure 12. The places for which the data are summarized are the new eleven places. Likewise the summary statistics below this table repeat the format described above. Note that the average distance of the places to their closest center is now 5.664 units compared with 7.967 for the original eleven places. This is a 28.9 per cent reduction (see bottom of Figure 14).

Figure 14 shows the assignments to the new centers of the 675 places in the two ways described earlier (see Figure 12).

In Figure 15, the effect on both centers and places of adopting the new eleven centers identified by the analysis in comparison with the original eleven centers is shown. The comparison divides the data into three sections. First (see top of Figure 15), the new centers identified by the algorithm are described. Nine of the eleven original places were replaced in the analysis. Thus, there are nine new centers, nine "old centers" and two centers that were present in the original set of eleven and are called here: "remaining centers." These places, shown in the middle of Figure 15, are described according to their status at the beginning of the evaluation and their status at the end (see "end set" in Figure 15).

In Figure 16, a comparison is made of the change in status of all 675 places as a result of the analysis. How would people be affected by the adoption of the results of the analysis? In this illustration (see middle section of Figure 16), 45 percent of people would be unaffected by the change, 35 percent would be closer to a center and 20 percent would be farther than before. The figure shows that 22 per cent of places would be unaffected, 51 percent would be closer and 28 percent would be farther than before. Identification of the specific places and the degree to which they are affected is shown in the section "comparison of node assignments " (see top of Figure 16).

Fourth Day

On the fourth day, Dr. Ayeni defined eighteen analyses that he wished to undertake. Some of them, for example, were analyses to evaluate the locational efficiency of sequential ading of schools at various locations through time.

These analyses were all completed on this day. Note that the key to the ability of the system to provide solutions so fast is the fact that all the analyses, up to the final ALLOC 6B series, were performed only once. Their purpose was to organize the data for

speedy and efficient analysis of any problem subsequently identified. The input requirements to direct the solution of a problem are usually small, usually consisting of the identification of the centers that are to be evaluated; a description of the sources of the data sets developed earlier by the sequence: "DISTANCE, UNRAVEL, RETRENCH"; the identification of place-specific constraints such as discussed earlier; and the identification of the algorithm and the objective function that the user wishes Program ALLOC 6B to use.

Resources Used in the Case Study

We estimate that the resources required to produce the eighteen analyses requested by Dr. Ayeni were:

Professional time: seven person days.

Clerical time (data encoding): two person days.

Computer time: approximately $20 per analysis and approximately $250 for the development of the geocoded data files.

These resource estimates presume that the software system is operational on the computing installation (in this case an IBM 370), and that a person is available who is trained in the use of the system and knowledgeable about the theory and methods of location-allocation analysis and of the specific computational techniques that are used in the Hillsman ALLOC system.

7. APPLICATIONS IN DEVELOPING COUNTRIES.

In the remainder of the paper I review applications of location-allocation models and comment on some areas of locational decisionmaking where these models would appear to be useful but where they have not yet been used. The paper concludes by suggesting areas of research that would improve the potential of existing optimizing methods for improving the location of services in developing countries.

8. EDUCATIONAL PLANNING.

With population increases of 25 percent per decade typical of most developing countries outside East Asia, the growth of their school age population is increasing rapidly. A majority of these children are in rural areas, traditionally the poorest served with educational facilities. Many countries have instituted compulsory primary education and have begun a program of location and construction of schools. India alone, for example, 37,291 high schools, 73,725 higher primary schools, and 267,366 primary schools were opened between 1951 and [illegible] (see Government of India 1980).

The ability of primary children to travel is so restricted that the objective in locating primary schools is usually to find locations

for which the maximum number of children are within walking distance. In areas with a dispersed population this has been found to be about 4 kilometers, though in areas of concentrated populations the limit is often planned to be 1.5 kilometers (see Gould 1978, pp.84-92). Wherever the settlement system is nucleated, such small radii of spatial coverage correspond with the size of the settlements so that a simple procedure for approximating the solution to the location set covering problem, (see Church and ReVelle 1974), is to select the largest places not yet served. In selecting the largest settlements that do not yet have a primary school, the increase in children that are within walking distance of a school will be the greatest given the number of new schools. The result is identical to that produced by using the greedy adding heuristic algorithm (GAS) (see Church and ReVelle 1974, Eaton et al. 1981).

When the settlement pattern is not nucleated, knowledge of the exact location of the school age population is usually not available and is often presented in National Censuses as "Census Village Population"--a common euphemism for what would be called an "enumeration district" in Western Censuses. Given the information gap, the rapid shifting of populations at this local scale, and the performance of the settlement ranking "algorithm", a good case can be made that location-allocation algorithms are not the most appropriate tools for planning the development of primary educational facilities when children walk to school.

Middle-level schools, high schools and colleges, however, are facilities which serve larger areas and populations, and it is a more difficult problem to select the combination of locations for them that will optimize some objective. There are many more feasible locations for high schools, for example, than could or should be selected. The number and location of students who will receive a high school education is related to the local availability of a facility. These are service systems in which the demand is responsive (elastic) to the locations of the facilities so that the degree to which the goal of increasing the proportion of students who graduate high School will be achieved, will be strongly affected by the locations of the facilities. The same resources located differently will lead to different proportions of students completing High School. At higher educational levels than the primary school, information for location planning is more readily available because the demand for higher level schooling is strongly related to the output of students from schools at the level just below it.

In the Western educational planning literature, mathematical models such as linear programming have been used to optimize the spatial assignment of pupils to schools; but in such applications the locations of the facilities are known and fixed. It is a coincidence that the development of location-allocation models occurred in the 1970s when in Europe and North America the phase of school facility expansions had just finished. Since then, school racial "balance" and facility closing have been major planning issues in many of these countries. Consequently, optimal location methods were rarely employed in school facility planning in Developed countries.

School Location Planning.

Starting in 1971, The International Institute for Educational Planning (IIEP) of UNESCO organized a project "on planning the location of schools within the context of overall plans for the development of educational systems " (see Hallak 1977, p.7). The purpose was to identify factors relevant to the optimal location of schools, to develop a methodology for finding such locations that would be sufficiently flexible to accommodate the particular conditions of member countries, and to apply the methodology in selected cases. IIEP sponsored case studies, each of which was to end with "proposals for rationalizing the location of schools," (p.7). Between 1973 and 1977, it published ten case studies from four continents (for a list of these case studies, see Hallak 1977, p.8). The IIEP study recorded how location decisions were made in about fifty countries:

> "It confirmed, as was to be expected, that many countries, despite statements to the contrary, are not doing any educational planning and that their school maps are the results of hazard, improvisation or laissez-faire attitudes." (p.22).

In nine of the eleven countries where intensive study was undertaken, IIEP found that locational decisions were: "'forced' as a result of pressure from the users or from other groups of locally interested people." (see Hallak 1977, p.32)

In reviewing "techniques for deciding on localities for new schools," the IIEP study considered but rejected optimizing techniques on the grounds that the approach of linear programming used in developed countries, was useful only for "alloting populations to the various fixed-capacity schools;" that "the amount of computer calculating time involved exceeds reasonable limits;" and that " the 'economic optimum' arrived at is not always acceptable, because putting it into effect would lead to psychological, social or political difficulties." (see Hallak 1977, p.222)

Consequently, the project considered it "preferable not to take a theoretical model for our investigations, but to proceed empirically rather using a system of continuous approach, and applying a set of criteria from among those available." (p.222)

By viewing the relevant analytical techniques as linear programming methods, the IIEP study failed to identify the appropriate analytical methods for planning the location of schools even though location-allocation methods were well-known by that time and several review articles had appeared (see ReVelle and Swain 1970; Scott 1971).

The IIEP Method. The technical basis of the IIEP approach is the "school map." This is to be interpreted literally as a map or maps on which are marked the information thought to be relevant to the characteristics of the area and the questions being asked. Their "empirical procedure" led to the identification of a list of relevant criteria, but how these criteria were to be implemented was evidently an art that was learned in the field:

> "In deciding on the location of schools, account is taken of the road network and of the limits on distances children have to travel." (see Hallak 1977, p.98)

or:

> "...it was possible to make proposals for schools at the (demographic) 'centres of gravity' of each sector, ... In a second stage, the ideal map so arrived at was compared with the existing school map (1971), after which definitive proposals were put forward including one for dividing the county up into new catchment perimeters." (p.223)

The study explains why catchment areas should be thought of as hexagonal in shape rather than circular, and gives the formula for computing the area of a hexagon. Pointing out that, in practise, non-uniform population densities, the characteristics of route networks and the varying characteristics of schools will all distort any theoretical system of uniformly spaced schools, the study concludes that:

> "what has been said on catchment areas from a theoretical point of view is not of practical value when it comes to actually finding solutions for school-map problems in a particular area." (see Hallak 1977, p.152)

No method is given for dealing with the geographical variation of the three factors cited: population density, route structures, and school characteristics. These are the very characteristics that location-allocation methods are able to integrate in a formal model. None of the case studies interpreted the problem as a multiobjective location problem, (see ReVelle, Cohon and Shobrys 1981).

Three years following the publication of the IIEP study, according to a working document which reviewed IIEP activities in this area throughout the world, recognition that these optimal location methods were available and were relevant to the task of school location planning had still not occurred (IIEP 1980a). More recently, the term "micro-planning" has appeared in IIEP literature. Though including school-mapping as a major component, its emphasis is on the devolution of decisionmaking and planning to the local level. As such, their approach to methods of analysis de-emphasizes the evaluation of system-wide effectiveness as a component of school location planning and emphasizes the relevance:

> "of using work methods ranging from the field survey (in schools, families, firms) to the people's active participation in formulating its problems (research-action)." (see IIEP 1980b, p.10)

A later document describes the "development and improvement of techniques for planning at local/regional level," but shows no sign that IIEP had seen the relevance of methods of optimal location to its work (see IIEP 1981, p.3).

The World Bank Method. The World Bank also sponsored an investigation that led to "Guidelines for School Location Planning," (see Gould 1978). Although this work also makes no reference to the use of location-allocation models, it does focus more sharply than the IIEP studies on the problems of reconciling "geographical range" and "geographical threshold" values. The "range" refers to the central place concept of the farthest distance that pupils will be expected to travel, and "threshold" describes the minimum number of pupils at each grade level for which the school is designed. Gould gives an account of the systematic relationships that exist between population density, enrollment rate and range in an ideal system, and is essentially solving a primitive location-allocation problem for the hypothetical situation he assumes (see Gould 1978, pp.7-23).

In reviewing World Bank Educational Projects, Gould concluded that before 1974, "the criteria according to which a specific location is chosen or to which a general distribution is made have generally remained implicit in the project reports, or else have warranted slight attention in comparison with the wider educational and economic issues raised by the project." (see Gould, 1978 p.47) Citing 15 specific projects in 14 countries, Gould states that, after 1974, an increasing number of World Bank educational projects specifically considered criteria for the location and distribution of schools. In none of these cases were location-allocation methods for finding optimal locations used.

School Location Planning in India. So many countries were involved in the IIEP study that it is difficult to find a developing country that was not influenced by their work and its recommendations for appropriate methods for locating schools. One exception is India, which chose not to participate in the IIEP study. In the 1960s, India had established national criteria for the appropriate location of its schools (see NCERT, 1970). Its National Council of Educational Research and Training (NCERT) had conducted national educational surveys in 1947, 1965, 1973 and 1978, which had established in each year the accessibility of the population to educational facilities of different levels (see NCERT 1978). It had also developed training materials for preparing plans for proposing new locations for schools. These procedures were developed with a view to manual rather than computer implementation. They are interesting in that they use the principle of "greedy-adding" (see Church and ReVelle 1974) within the areas which are not within the coverage distance set as the criteria for adequate service. This is a heuristic location selection principle that is known to produce good location patterns if properly implemented. As Tewari and Jena (1983) have shown, however, their rules for location selection advise the selection of the place with the largest population within an area that might contain several places outside the recommended distance coverage. Unlike the situation discussed earlier for primary schools, when the maximum distance a child can walk to school becomes between 5 and 7 kilometers, as it does for secondary schools, the NCERT method of selecting the largest populated place farther from an existing school than the maximum distance will often result in locations being

selected that are substantially suboptimal with respect to optimal population coverage. Tewari and Jena have evaluated the plan produced by educational planners in one Indian District who used the NCERT methods to propose the opening of three new higher primary schools at specific locations. They used a heuristic location-allocation model (see Teitz and Bart 1968) to find three optimal locations using the NCERT criteria of maximum population coverage and compared the result with the educational planners' proposed locations. They found that the expected enrollment in the three schools would be 55 percent greater in the locations selected by the algorithm, and that the reduction in distances that students would have to travel to reach the schools, after opening the three schools, would be more than twice as great in the case of the optimal locations. Although this is only one case study, it does illustrate the benefit of the use of optimization methods and raises the intriguing possibility that there exists a large potential for improving the methods suggested earlier by IIEP and The World Bank.

Context Free Methods.

It was not recognized in educational facility planning in developing countries that methods for finding optimal locations for educational facilities were special cases of the general model for finding optimal locations for any service facility. ReVelle has referred to such methods as "context free methods " (ReVelle et al. 1977). In asking whether optimizing methods were available, Hallak examined the optimizing methods being used in the developed countries at that time. These were linear programming methods which were being used because the question facing developed countries at that time was not how to find good locations for new facilities, but, rather, how to optimize the assignment of pupils to schools and to increase the efficiency of resource use. These were not the questions faced by educational planners in developing countries. As ReVelle and Swain (1970) had shown, linear programming methods could also be used to find optimal locations.

9. REGIONAL PLANNING.

Integrated Area Planning.

By about 1970, there was widespread recognition in many developing countries that local economies were village-centered, and that further development would require these village economies to be connected to sources of agricultural inputs, vocational training, social services and markets for their agricultural surplus (see Grove and Hussar 1964; Johnson 1970). Investments in infrastructure would have to be made at locations from which the returns would be greatest. Jonnson (1966), discussing the development of market towns in India, wrote:

> "roads, electric power, water supply, and vocational training facilities should be spatially planned to serve the needs, and to increase the economic effectiveness, of the great mass of people

who now live in the villages. (p.149)

and that:

> an adequate number of market and manufacturing centres, each adapted to the present and prospective spending power of suitable population aggregates, and located within convenient travel distance, will require a very long time to grow up autonomously, and there is no assurance that a network of such centres ever would emerge. What is called for, to set this transforming process in motion, is intelligent coordination of public and private investment policies by means of imaginative planning conducted by local, State and Central Government Agencies... (p.147)

Applications of Optimal Location Models.

First in India, and later in Indonesia and Sierra Leone, it was argued that the problem of identifying settlements which should be developed as local service centers was a problem that could be solved by optimal location methods. In 1970, the Government of India developed a "Pilot Research Project in Growth Centres " (see Shah 1974), to develop "a broad research methodology and pattern for identifying emerging growth centres, and to indicate how the growth potential of these centres could be promoted ..." (see India, Planning Commission 1970, p.229). Among the team of researchers engaged on this project was a spatial planning team. Their work was reviewed by Fisher and Rushton (1977). This team used location-allocation methods to identify a spatial hierarchy of potential service centers that would meet the separate spatial requirements, defined by different sectoral agencies, for effectively serving the basic needs of the rural population. They also examined the spatial effectiveness of the locations of several services in a study region in Western India by comparing the average distance to the closest existing service site in the region to the average distance in an optimal system as computed by the algorithm. They discovered that banks and post and telegraph offices required that people travel on the average more than 40 percent farther than in an optimal system. To reach hospitals, the population had to travel 21 percent farther; and to police stations, only 10 percent farther. In other words, when the consumer had to travel to the service, the evidence indicated that the providers of the service were insensitive to their needs for access, but when the provider of the service had to travel to the consumer (as is often the case with police), the provider succeeded in locating their service to be accessible. Whatever the interpretation, these results show that existing services in a typical rural area differ in their geographical accessibility to the rural population, and that the need for intervention to correct for deficiencies in the accessibility to a particular service will vary from activity to activity and from area to area (see Fisher and Rushton 1977, p.359).

A pioneering study by Patel (1979) investigated the selection of service centers in a Taluka in Gujarat, India. The objective, determined in consultation with government officials, planners, local leaders and voluntary workers, was to select locations from a list of eligible places that would maximize spatial population coverage for a

given budget. The cost of developing each service center varied from site to site. The problem was formulated as a set covering problem of integer programming. With location selections made from 44 sites serving the 237 villages in the Taluka, the objective function was to minimize the service center development cost within the constraint of complete spatial coverage within the maximum distance limit. The problem was solved iteratively for eight different values of the maximum distance. By finding the minimum value of distance that had a solution within the budget limit, the required optimal location set was identified.

In Bali, Indonesia, a study by Kusumadewa, Fisher and Wiyono (1977, p.24), found that the locations of high schools in Bali required students to travel approximately 10 percent farther than in an optimal system. Patients to the special hospitals had to travel 17 percent farther. Although in neither the Indian nor the Indonesian cases were the computed location patterns adopted without modification, they were used as a planning standard against which any locations selected by more traditional procedures were evaluated.

In Sierra Leone, Harvey, Hung and Brown (1974), used a p-median heuristic algorithm to define a hierarchy of service centers. This algorithm operated on a base of agro-urban "communities" that had been selected by a Monte Carlo simulation procedure. Since such a procedure reduces the credibility of any results that follow, the authors offered their approach as an example of experimentation with scientific tools that may assist planners and decisionmakers. There are several other applications of location-allocation methods in regional planning (see Banerji and Fisher 1974a and 1974b; Fisher and Rushton 1979; Roy and Patil eds. 1977).

After 1975, with the exception of the work of Patel (1979), the use of location algorithms as an aid to settlement planning stopped. In India, the Central Government decided that the regional planning task was a function for state level governments to undertake. These had their own professional planning groups who were unfamiliar with the methods. Consequently, the momentum among practising planners was lost though work continued in a number of research institutes within the country.

The A.I.D. Approach. Elsewhere, beginning in 1976, an ambitious program to improve planning methods for bringing urban service functions to rural populations was organized by the Agency for International Development (AID) in a project called "Urban Functions in Rural Development" (UFRD). The blueprint for this project, commissioned by AID is described in Rondinelli and Ruddle (1978). They proposed experimentation with a variety of methods in different developing country contexts. The methods they proposed included a broad range of descriptive statistics including the Guttman Scalogram describing and ranking the occurrence of functions in urban places. They did not include any optimizing methods for selecting locations for activities.

Their methods were applied between 1977 and 1982 in case studies in The Philippines, Upper Volta, Cameroons, Guatemala and Bolivia (see Evans 1982; Rondinelli 1979 and 1980; Rondinelli and Evans 1983). The ten step methodology that evolved in these studies (see

Rondinelli and Evans 1983), does not include any application of optimizing methods. Unlike Hallak who recognized the need to explain why a planner who was trying to optimize resource deployment would not use an optimizing method, the UFRD projects assumed that it was possible to find optimal resource deployments from descriptive statistical techniques.

The conclusion on the application of optimizing methods in developing countries for making location selections in regional planning tasks is thus a story of a promising beginning in India, Indonesia and Ghana, with a loss of momentum when, in the AID projects, there was a return to the use of older methods that pre-dated the development of optimum location methods from 1963.

10. HEALTH PLANNING.

Many studies have concluded that primary health care does not reach the majority of people in rural areas of developing countries. Foremost among the reasons usually cited for inadequate coverage of these populations with health services is the factor of poor geographical accessibility (see Bose and Desai 1983, pp.116-19; World Bank 1980b, pp.39-42; Golladay and Liesen 1980; Indian Council of Social Science Research 1981; Stock 1983). It has been a policy of many governments to increase the accessibility of their rural populations to health services by expanding health service sites or by more widely distributing health workers. These policies are consistent with the Alma Ata declaration on health to which most developing countries are signatories (see WHO-UNICEF 1978; Morley Rohde and Williams 1983). Location-allocation models are appropriate for aiding the locational choices that need to be made in implementing these policies.

Applications of Optimal Location Models.

Latin America. A series of studies in Latin America has used location-allocation models to improve the proportion of the rural population that are within a given distance of primary health services. Bennett, Eaton and Church (1982) analyzed a small region in Columbia shortly after a team of health planners had completed a study to locate health sites from which health paraprofessionals would visit surrounding villages to provide basic primary health services. They interviewed the planners and learnt of the standards that they had used in making their location choices. They had, for example, limited paraprofessional "travel to 15km or two hour walk round trip, whichever came first " (see Bennett, Eaton and Church 1982, p.65). Using a "maximal covering" location-allocation algorithm (see Church and ReVelle 1974), they were able to find a set of locations for the health centers that performed better than the sites selected by the planners themselves, as evaluated through their own terms of

reference. The analyses were repeated several times. In each case, a particular constraint on selection of the sites, such as the presence of electricity or potable water, was deleted so that the effect of including that constraint on limiting the proportion of the population who could be reached by a paraprofessional health worker would be known. From each analysis it was possible to find the maximum proportion of the population who could be reached, given the set of site constraints and the number of sites that would be needed to reach that level of population coverage.

In locational decisionmaking, there is a natural bias toward the incorporation of many site specific factors because these are more easily measured than geographical access, which is often known only as it is observed in the distances traveled by users of a system. In any case, the site specific factors are often "represented" in the location decisionmaking process by interested individuals. The result, so Bennett, Eaton and Church show, is that in their efforts to take into account the many site specific factors, the planners developed a plan that was poorer with respect to both geographical coverage and desirable site factors than the computed plan, the data requirements of which did not require a complete survey of villages such as had been considered necessary by the local health planners--a task that consumed twenty person years of their professional time (see Bennett, Eaton and Church 1982, p.64).

The paradox of finding a superior solution using less data is one that several authors have noted. In an attempt to incorporate more and more information into decision making, the planner has to implicitly weigh and trade-off advantages gained with respect to one criteria with losses incurred with respect to another.

A related study by Eaton et al. (1981), used a heuristic maximal covering algorithm to find new health sites, which if added to the 28 existing sites in their study area, would most improve population coverage. This problem of incremental siting of new facilities is one where the algorithm can be used as a screening device to assist in the selection of new sites. In this respect, the role of the algorithm changes from the identification of a set of places that are optimum to an aid in the decision making process. Some authors have argued that this is one of the most useful roles that such methods can play (see Brill 1979; Schilling, McGarity and ReVelle 1982).

A number of authors have pointed out that most health service systems involve a geographical hierarchy of personnel and facilities in which it is often assumed that the first contact of the patient with the health system might occur very close to the patients home (a village level health worker or paraprofessional), and that close to the village would be a health site with full time health professionals and some basic facilities for providing care for emergency and other common problems. At a greater distance might be a hospital and, even from here, referrals might be made to a higher level health service site at some more distant place. Narula and Ogbu (1979), Dokmeci (1973 and 1977), and Moore and ReVelle (1982) have used location-allocation algorithms to define and solve this problem.

The case described by Moore and ReVelle is particularly interesting in that they postulated that the distances that patients

would be willing to travel for the same kind of health problem would differ according to the level of health center to which they might travel. This is an element of realism, consistent with many empirical studies, that previously had not been incorporated in the objective function in location-allocation applications. These authors explain how, through a simple data editing procedure, such aspects of reality can be incorporated in the objective function.

A second innovation in the Moore and ReVelle study, which addresses the question of defining an optimal hierarchy in a two tier system of health service sites in Honduras, is that costs are assigned to the construction and operation of each type of health service site. The location-allocation algorithm is used to find the number, and their location, of each type of health site such that the maximum proportion of the population is within the acceptable travel distance of a site given any fixed amount of funds that can be invested. This might be compared with Patel (1979) who found the minimum maximum distance that all people would be from a set of locations that could be developed for a given budget. Moore and ReVelle (1982) concluded that, contrary to conventional wisdom which holds that: "each increment of investment should yield a steadily smaller return in effectiveness or coverage," there are positions on the level of investment chart for which "at a slightly higher level of investment the increase in coverage with a unit of investment may take a decided jump in value " (p.780).

Working in Honduras, Moore (1982, pp.120-33), examined the current locations of auxiliary nurse posts. He found that 59.7 percent of the population of the study area were within 90 minutes of the 66 facilities. Results from the maximal covering algorithm (see Church and ReVelle 1974) showed that 66 sites optimally located would have reached 68.2 percent of the population within the same distance, a 14 percent increase in efficiency. These sites would, however, have required the relocation of 28 of the 66 facilities. In interviews with government officials, Moore found them convinced that such a plan would be politically infeasible to implement because "the resentment created by closing facilities would probably be greater than any goodwill created by opening others " (see Moore 1982, p.135).

He also showed that the same population coverage as the current pattern of nurse posts could have been achieved with a 26 percent reduction in the number of sites. In contrast, he found that the Physician-based clinics in the study area were close to optimal in meeting the criteria of maximizing the proportion of the population within a radius of 4.5 hours. His own assessment of the utility of these analysis systems is that they are more useful for guiding decisions about future allocation and siting of facilities. He notes that: "the Honduran Economic Planning Council plans to find funds to undertake a series of orientation programs for sectoral planners, which present an introduction to these methods and how they can be used " (p.213).

Africa. In a study in the Eastern Region of Upper Volta, Mehretu, Wittick and Pigozzi (1983) used a heuristic location-allocation model (see Teitz and Bart 1968), to find locations of health service sites. Their objective was to locate clinics to minimize the aggregate distance travelled by the population to medical centers subject to the constraint that no one would have to travel more than five kilometers (see Hillsman and Rushton 1975). The population, located in 635 Census defined villages was, however, grouped into 94 small areas consisting of clusters of villages (called "programming units") prior to analysis so that the algorithm found optimal locations within these arbitrary planning area units. The explanation given in the paper incorrectly states that such boundaries are necessary so that the algorithm will select only populated areas. Wittick explained this constraint (personal correspondence Sept. 21, 1983):

> The reason for the initial grouping of villages into PU areas was strictly a political one; that is, the project was funded by the Upper Volta government and they had decreed that villages were to be aggregated into these planning units, and all planning studies were to incorporate this unit of aggregation. I agree with your comment that it is not a logical choice of unit, and it is rather inconsistent with the methodology used.

Unfortunately, the constraint that optimal sites should serve areas with fixed, arbitrary boundaries, is likely to lead to a location pattern that is poorer with respect to any given objective, than if the areas had not been defined. This fact is well-known in location theory (see Leamer 1968). Why then should governments insist that areas within fixed boundaries should be served when the boundaries are purely statistical artifacts?

Upper Volta is not the first government to insist on such a procedure even though it is damaging to the accomplishment of the very goal that it was designed to meet. Governments will often designate small areas as regions to be served in an effort to force compliance with their goal of decentralizing the location of a service. The regions are often data units which local areas must use in reporting back to their government the locations of the service. The government then uses the data to assess the degree of success of any of their policies designed to achieve decentralization. Perhaps these are good reasons for forcing locational decisions to be made in relation to small regions. Yet the price in terms of locational inefficiency can be considerable.

India. Rushton (1983) studied a similar case in Karnataka, India. There the state, following the publication of the 1971 Census, asked the District Health Officers (DHO) to define contiguous areas with 15,000 population and designate them as "primary health unit blocks." They then periodically asked each DHO to describe how many blocks in their area did not have a primary health service unit and, from time to time, they made additional funds available to locate health units in the blocks where no such unit existed.

Rushton used a location allocation model to compute new locations for health units without the administrative constraint that they must be located in the unserved blocks and repeated the analysis including the constraint. In both cases the objective function was to

locate the health units so that the average distance of the population to their closest health service site was least. The percentage difference between the two solutions was, therefore, a measure of the cost of the government's constraint that health sites must be located in the arbitrary regions defined by the health planners in 1971. Results showed that the persons affected by the new locations would have to travel, on the average, 40 percent further to reach the locations that were optimal, given the constraint that each population district must have a health site.

Upon investigating a number of cases in field visits it was clear to him that some population blocks without health units have populations that are well located with respect to health units in adjacent blocks. Other population blocks, however, which already have health units have substantial populations that are geographically inaccessible to these health units. The government's intention in defining the areas then was to ensure that the location of health services would be geographically accessible to the population.

The result illustrates the principle that is well-known to analysts who optimize functions: adding a constraint to decision-making will never improve the attainment of the intended objective but may well adversely affect it. The argument that is sometimes used to justify imposing the constraint is that it leads to the identification of locations which, though not the best, are better than the worst decisions that could be made if the constraint were not there. This would be true even when the worst locational decisions were made subject to the constraint. In practice, decision-makers might reasonably hope that by restricting the choice to a well-defined set of alternatives, a better decision will be made.

Working in the same area, Rushton and Krishnamurthi (1983) used location allocation algorithms to compute the locational efficiency of health service sites that had been chosen during the past decade. Accepting the location of health care sites at the beginning of the analysis period (1971), they used the algorithm to identify the locations which, if added to the existing set, would most improve the average distance of people to their closest center. Using the algorithm to locate the same number of new centers as were located in the succeeding period, a comparison of the two sets of places shows the relative efficiency of the locations actually selected in the period. The results showed that the sites selected from 1971-1976 were 70 percent efficient, compared with 77 percent efficient in the period 1976-1979, and 62 percent efficient from 1979-1981.

They explained the recent decline in the quality of locational decisions as a result of the "regional constraint" introduced by the Government in 1971 and described above. Although it operated throughout the period studied, the constraint became progressively more of a handicap to efficient locational decisionmaking as more and more sites were selected and the options available to decision makers became fewer as they sought to find viable health service sites within these arbitrary regions, some of which had no recognizable geographical focal point from which services could effectively reach the surrounding population.

They also showed that, although the most recent locational decisions had been less efficient than earlier decisions,

paradoxically, the locational efficiency of the entire health service system had improved considerably over the decade. The percent inefficiency in the system, as measured by the average distance of people to their closest health site, declined from 17 percent in 1971 to 12 percent in 1981. Considering the new health sites which became available in the study area during the decade, people in the area became 38 percent closer to a health site during the decade. These results show that geographical accessibility can be improved in an area with poor accessibility to a service even though the actual sites selected are poor in comparison with other locations that are rejected. They concluded that this finding shows the insensitive nature of the measure of locational efficiency for a total system of places in comparison with measures of the relative locational efficiency of the marginal places selected in each period.

Conclusion. Unlike the educational sector, the health sector provides a number of examples where location-allocation models have been used to evaluate methods of making location decisions, to assess the overall locational efficiency of the system of health services in an area, and to assess the effect of constraints on decision making imposed by bureaucracies attempting to control the quality of the decisions that are made.

11. CONCLUSIONS.

Achievements.

Despite the views of many, that location-allocation methods were too sophisticated for use in most developing countries, enough examples exist in developing countries to show that analyses are possible for most situations. The analyses which have been completed have sometimes found the locations needed, but, more usually, they have furnished valuable help in the decisionmaking process. In several cases comparisons of the results of these analyses with the results of other methods have shown the superiority of location-allocation methods for achieving the same objectives defined by the decision maker.

These examples show that required data is generally available. Where location problems were solved using other techniques, a wider range of data than that required by a location-allocation model was used. The examples also show that suitable computer facilities exist in most countries to perform the necessary analyses and that professionals from a variety of disciplines are usually available among the nationals of most countries with skills to perform these analyses.

Opportunities Lost.

During the past ten years, many institutions had recognized the importance of improving locational decisionmaking in the area in which they were engaged. Even though the literature of location-allocation modeling was wellknown within the professions of Regional Science, Geography and Management Science, and although most of these institutions had access to the advice of professionals in this area, they often insisted on using less appropriate methods, often claiming them to be simpler and more appropriate to the conditions of developing countries. The documents describing these cases show an almost universal groping for ways to implement the same concepts that had been so successfully operationalized in location-allocation models more than ten years earlier: how to select locations to meet distance limits, capacity thresholds and general accessibility to the population. These phrases occur again and again in these documents as their authors make progress in rediscovering a literature that already existed.

A second opportunity lost is illustrated by the narrow purpose and use of these methods in the published applications. Even though the methods were generally used as an aid to decisionmaking, decision-makers rarely used the flexibility of these models to explore alternative options or their own past pattern of locational decisions to improve their performance in the future.

Analysis Objectives.

Location-Allocation models can be used for a greater variety of purposes than those realized in the applications described above. They can be used not only to select locations that optimize given criteria, but also can be used to measure many important aspects of current, planned or computed locational systems. Three purposes are relevant to improving the geographical accessibility of rural populations to basic services:

Assessing Current Levels of Access. The purpose here is to evaluate the levels of geographical accessibility of the current system and to compare current norms with any distance accessibility standards that exist. This purpose leads to the asking of a typical set of questions: How many service sites would be needed to provide the same level of geographical accessibility as the current system? How many of the current service center locations would be retained in such an optimal system? Is there a recognizable regional shift in resource allocation when the optimal location pattern of resources is compared with the present?

To answer these questions, the analyses will often begin by computing "solution spaces" for the study region for the "demand" pattern that needs to be served, (see Fisher and Rushton 1979).

Evaluating Recent Location Decisions. To accomplish this purpose, analyses are needed that will compute optimal locations for conditions that existed in the recent past. These analyses should replicate recent location decisions to determine whether they were effective, compared with optimal locations selected by the algorithm, in bringing the system into conformance with standards. These results will show whether inequalities in access have been reduced to the greatest extent possible given the limited resources expended.

Identifying Future Locations. This purpose involves the identification and prioritizing of further locations which, if added to the existing service locations, would bring the system closest to the stated standards. Planners of an improved service system need to know: What is the increase in geographical accessibility of the last center added to the optimal set (the marginal center)? How does this change as the number in the optimal set changes? Which settlements and areas would use the service at any place? What are their sizes, their population characteristics, the local geographical accessibility conditions? They also need to know: What is the distribution of distances that people will have to travel in the "new system" as compared with the "old"? How many people will travel more and how many less distance in the two systems? How many people are adversely affected and by how much? How many people would be expected to use the same service center that they had previously used? If one is interested in different groups of people (for example, young and old, high caste and low caste, rich and poor), how are these groups affected by the analysis plans? Are they located in unserved or underserved areas?

These "context-free" objectives that can be asked of any group charged to develop plans to improve the geographical accessibility of a rural population, provide the data that will allow effective planning of a service delivery system. Too frequently the activities at a service site are organized and evaluated outside the context of the local conditions facing the providers and consumers of the service. The paradox is that by making the questions context dependent, one can make the evaluation system context free. Computerized analysis systems provide measures for most of these objectives (see Hillsman 1980; Hillsman and Dwarakinath 1984; Rushton, Goodchild and Ostresh 1973).

Research Needs.

Location decisionmaking in developing countries would benefit from research in a number of areas of location-allocation modeling.

Selecting the Objective Function. If the purpose of a locational planning effort is defined as selecting locations and activity patterns within resource constraints and other exogenously defined constraints to meet defined behavioral outcomes, then the choice of objective function is no longer a simple task. In the case of educational planning, the intent may be to minimize the school dropout rate (maximize attendance), but research is needed to establish how locational arrangement and school dropout rate are related. Gould (1978) reviewed nine of the IIEP case studies, all of which had collected data on distances students travel to school, and concluded that: "Where there is a relatively even distribution of population within a catchment area the proportion attending school declines with distance from the school, but due to the difficulty of obtaining sufficiently disaggregated population data, this distance decay function cannot be quantified." (p.88) If such a decline does exist, the use of many objective functions, such as distance minimization or population coverage within a distance range, would lead to the selection of school locations that would not maximize attendance (see ReVelle and Church 1977. Yet, this is the goal of many school location planning activities (see World Bank 1980a, p.27).

Even if distance impacts were to be incorporated in location-allocation models as transformations on the function of distance, enough evidence exists that utilization of a service depends on far more than simple distance to a resource location. If, for example, we do not know how the health of a given population is affected by the locational arrangement of health resources, how can we write an objective function that, if optimized, would give the locational arrangement that would, if adopted, improve health most? This problem is more acute in most developing countries because of the lack of knowledge about the determinants of the use of a service and because we are much less confident that any direct observations we make on service use represents a stable pattern of use that would be preserved in a new environment of opportunities. It is not satisfactory to assume that current patterns of spatial interaction will be found in the future.

Some research needs are linked to the sectors in which the applications will be made. Experience is needed in each sector to solve the substantive problems that arise that are sector specific. For villages located at various distances from a middle school, for example, what will be the expected proportion of students finishing primary school who will continue to the middle school?

Partial vs. General Location Problems. Most service location problems in developed countries can be fairly realistically cast as partial location problems. That is, the constants in the problem are the context of other service activities even though we are usually aware that this context too is likely to change in the long run. In developing countries, however, one is acutely aware that change is all around, and that it is safe to assume that nothing can be assumed to stay the same for very long in the arrangement of related services and the communication system supporting them. If true, this is a difference of degree rather than of kind between developed and developing countries. Nevertheless, our capacity to deal with the

dynamics of such situations is very poor. We have little experience of trying to model such dynamics and most experienced researchers can cite cases where the assumptions of a year ago have been rendered invalid by changes that seem to be, in principle, unforcastable.

The Locational Efficiency of Current Decision-Making. Very few studies have analyzed the locational decisions of the recent past. Far more common have been the system-wide evaluations of locational efficiency. Interesting though these results are, decision makers can comfortably face such results knowing that they are not directly responsible for all the locational decisions that have preceded them. For example, analyses that accepted the locations that were made prior to the present plan period, and then computed the locations to be added to that set, would put the decisionmaker in the position of being concerned that it is his decisions that are being examined and that any locational efficiencies are to be regarded as either his immediate regret value or as an inefficiency that can be justified by circumstances that were not a part of the analysis. Research is needed not only on the locational efficiency of recent locational decisions but also on the effectiveness of locational decisions made by different processes of decisionmaking. The "school location planning" literature, for example, emphasizes the participation of local authorities in assuring "the equitable and efficient distribution of resources " (see World Bank 1980a, p.27). How does their participation affect the quality of locational decisions?

Location Models as Decision-Aids. It is still true, as Teitz (1968) observed almost twenty years ago, that "the theorist of public facility location finds himself inevitably drawn away from the problem of location of the individual facility and toward the structure and location of the entire system of facilities within the area..." (p.38). Yet, it is clear that if regional science is to meet the wishes of one of its founders (see Losch 1954, p.508) and become: "an economic science more like architecture than like the history of architecture, creates rather than describes," then it must see in the location of the individual facility the key to the rationale behind the entire system of facilities. If a decision maker were to use, as a decision aid, the rule that a school should be added at whichever feasible location would most reduce the average distance of student travel, then the long run equilibrium location pattern would approximate the pattern of the p-median objective function. The decision makers would be acting out, in real life, the greedy adding p-median heuristic algorithm (see Cornuejols, Fisher and Nemhauser 1977).

Algorithmic Developments. I see no special algorithmic needs for applications in developing countries other than to note that computer hardware in these countries is extremely varied in type and vintage, and, in most cases, computers are smaller than those typically used for applications in developed countries. The rapid spread of micro-computers in both contexts holds some hope that the variance will be less in the future as software for location-allocation methods becomes available for micro computers (see Goodchild and Noronha

1983; Robinson 1983a and 1983b).

Geo-Coded Information Systems. Systems of data with accurate geographical coordinates and socio-economic data for small areas in machine readable form are virtually unknown in developing countries. Maps are often old, coverage incomplete, and with inaccurate communication links. What are the typical magnitudes of errors that are introduced when such data are used? Is it better to use distance measurements from coordinates than from road maps of dubious accuracy? Can distance functions be computed from which estimates of distances can be computed? (see Kolesar 1979; Love and Morris 1972 and 1979). These are important basic questions which need to be researched.

Training Needs. Since programs which teach Regional Science and Locational Analysis are very few in developing countries, there are still very few teachers of these methods. When professionals are trained, they often find themselves employed to provide planning help in a specific sector. Key decision makers in each sector typically interact most with other professionals in their sector and rely on professionals trained in their sector for help in locational decisionmaking. This leads to a situation in which, in a typical region, professionals in one sector may be knowledgeable about location-allocation methods and may have already assembled a geo-coded data system for the region, but who have no contact with the professionals from another sector in the same region. There is an urgent need for training materials in this area (see Eaton, ReVelle and Church 1977).

Future Applications of Location-Allocation Models.

These pioneering application efforts need to be expanded to cover larger territories, more sectors of the economy and of supporting services. Support has often come from a specific sector- health, for example. The result is a restriction on application only to problems of the sector from which study support was received even though the extra cost of analyzing the locational problems of another sector is usually very small after the basic geo-coded data set has been assembled. The objective in most applications has been to use the methods to find the 'optimum optimorum' location pattern for the stated objective function. In most practical applications, however, the objectives stated are not the only objectives of the decision makers, and they are usually anxious to explore alternatives that are good with respect to the defined objectives. They would like true "aids to decisionmaking" in which the algorithms will play a useful role in their process of evaluating alternatives and reaching judgments.

Acknowledgements.

Partial support for this work was provided by NSF Grant #INT 80-17879 and by The Program in International Development and Social Change of Clark University. I have also benefitted from discussions with Dr. Michael McNulty, University of Iowa, and Dr. V.K.Tewari, Indian Institute of Management, Bangalore, India. A very special thanks goes to Mr. S. Park who completed the analyses described in the illustration in Section 6. The data for this illustration was provided to us by Dr. Bola Ayeni, Department of Geography, The University of Ibadan, Nigeria. The design of the changes in ALLOC 6 was a team effort directed by G. Rushton and M.L. McNulty. Participating in addition to S. Park were Dan Berglove, A. Krishnamurthi, Don McKeagney and N. Sivagnanum. At The Indian Institute of Management, Bangalore, V.K.Tewari and S. Dwarakinath made some useful suggestions to us.

igure 1. Input File of the Program DISTANCE for Creating Inter-place Distance Matrix from Coordinates

```
//BLAQQQDS JOB (15001808,40),'I2PARK',TIME=3
//  EXEC FORTGCLG,REGION=350K
//FORT.SYSIN DD *
C                         D I S T A N C E
C
C     PROGRAM TO COMPUTE A DISTANCE MATRIX FROM CARTESIAN COORDINATES.
C     WRITTEN BY EDWARD L. HILLSMAN
C     DEPARTMENT OF GEOGRAPHY, THE UNIVERSITY OF IOWA, 1975.
C     DIMENSIONING INFORMATION
C     THE FOLLOWING ARRAYS ARE TO HAVE A LENGTH EQUAL TO THE NUMBER OF
C     NODES:
C     ID        ID NUMBER OF EACH NODE.
C     IX        X-COORDINATE OF EACH NODE.
C     IY        Y-COORDINATE OF EACH NODE.
C     IDIST     DISTANCES IN ONE ROW OF THE DISTANCE MATRIX.
C     IFMT      DOES NOT AFFECT THE NUMBER OF NODES THAT CAN BE HANDLED
C               BY THE PROGRAM.  IFMT IS USED TO STORE VARIABLE FORMATS.
C               IT IS MACHINE-DEPENDENT AND MAY HAVE TO BE CHANGED FOR
C               MACHINES OTHER THAN THE IBM 360 AND 370.
C     THE FOLLOWING FEATURES OF THE CODE ARE KNOWN TO BE MACHINE- OR
C     INSTALLATION-DEPENDENT:
C     (1)  IFMT AND FORMAT STATEMENTS 2000 AND 3300 (SEE NOTE ABOVE).
C     (2)  NREAD, NPRINT, AND KPUNCH ARE THE UNIT NUMBERS FOR THE CARD
C     READER, LINE PRINTER, AND CARD PUNCH, RESPECTIVELY.  THEY ARE SET
C     IN THE FIRST THREE EXECUTABLE STATEMENTS IN THE PROGRAM.
C     (3)  USE OF END= IN THE STATEMENT DIST    .
      DIMENSION ID(677),IX(677),IY(677),IDIST(677)
      DIMENSION IFMT(20)
      NREAD=5
      NPRINT=6
      KPUNCH=7
      WRITE(NPRINT,999)
C     READ CONTROL CARD AND FORMAT.
      READ (NREAD,1000) NODES,METRIC,NPUNCH,NWRIT
      IF (NPUNCH.EQ.0) NPUNCH=KPUNCH
      READ (NREAD,2000) IFMT
      WRITE(NPRINT,3000) NODES,NPUNCH
      IF (NWRIT.GT.0) WRITE(NPRINT,3050)
      IF (NWRIT.EQ.0) WRITE(NPRINT,3060)
      IF (METRIC.EQ.1) WRITE(NPRINT,3100)
      IF (METRIC.EQ.2) WRITE(NPRINT,3200)
      WRITE(NPRINT,3300) IFMT
C     READ ID NUMBERS AND COORDINATES.  CHECK FOR DUPLICATE ID NUMBERS.
      DO 100 I=1,NODES
      READ (NREAD,IFMT,END=900) ID(I),IX(I),IY(I)
      WRITE(NPRINT,3400) ID(I),IX(I),IY(I)
    .     .     .     .
    .     .     .     .     All lines of program are not shown here
    .     .     .     .
 6000 FORMAT(28H0DISTANCE MATRIX IS COMPLETE)
      END
```

Figure 2. Input Controls for Creating Matrix of Distance from Coordinates Using the Program "DISTANCE"

```
//GO.FT10F001 DD UNIT=DISK,DISP=(NEW,CATLG,DELETE),
```

opens disc file from unit 10 to store distance matrix

```
//  DSN=USER.A5001808.PARK.DSNIG.EUC675,
```

name of distance matrix for cataloguing on disc for input to UNRAVEL or ALLOC III, IV or V.

```
//  DCB=(RECFM=FB,BLKSIZE=7000,LRECL=70),
//  SPACE=(TRK,(500,20),RLSE)
//GO.SYSIN DD *
  675    2   10    1
```

control codes for this analysis:
675 places
2 means Euclidean distances to be computed
10 means the disc unit where the distance matrix will be written.
1 means - also make a paper copy of the distance matrix.

```
(3I5)
10001   73  820
10002  172  883
10003   78  808
10004  135  793
10005  150  770
10006  195  755
10007  190  742
10008  182  743
    .    .    .
    .    .    .
    .    .    .
40262  971  351
```

(3I5) describes the organization of the data: node ID's and X,Y coordinates

one of the 675 lines of input data: this one is for place ID 10006 which is located at X coordinate 195 and Y coordinate 755.

last data item- 675th place ID and coordinates

Figure 3. Sample Output of the Program "DISTANCE"

```
COMPUTE A SQUARE DISTANCE MATRIX FOR  675 NODES

WRITE THIS MATRIX ON OUTPUT UNIT 10

LIST THE MATRIX

COMPUTE DISTANCES USING EUCLIDEAN OR
 STRAIGHT-LINE METHOD
READ NODE DATA USING FORMAT OF:  (3I5)

ECHO CHECK OF INPUT DATA FOLLOWS

      ID          X          Y

   10001         73        820
   10002        172        883
   10003         78        808
   10004        135        793
     .          .          .
     .          .          .
     .          .          .
   40262        971        351

LISTING OF DISTANCE MATRIX

                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                
place ID  distance from 10001 to itself  distance from 10001 to 10002  distance from 10001 to 10009

10001    0  117   13   68   92  138  141  133  142  126  111  141  124  141
  169  179  187  191  205  223  249  278  284  301  319  298  325  332  328
    .    .    .
    .    .    .  remainder of distances from ID 10001 to the rest of the 675
    .    .    .  other places in the output data
    .    .    .

place ID  distance from 10002 to 10001  distance from 10002 to itself  distance from 10002 to 10009

10002  117    0   13   68   92  138  141  133  142  126  111  141  124  141
    .    .    .  remainder of distance from ID 10002 to the rest of the 675
    .    .    .  other places in the output data
    .    .    .
```

Figure 4. Input File of the Program "UNRAVEL" for Creating Inter-place Distance "strings" from the Distance Matrix Created by the Program "DISTANCE"

```
//BLAQQQUR JOB (15001808,50,,,,,0),'I2PARK',TIME=3,MSGLEVEL=(1,1)
//  EXEC FORTGCLG,REGION=250K
//FORT.SYSIN DD *
C                          U N R A V E L
C
C
C     PROGRAM TO CONVERT A COMPLETE DISTANCE MATRIX INTO A FORM WHICH
C     MAY BE USED BY ALLOC VI.(i.e., distance strings)
C     WRITTEN BY EDWARD L. HILLSMAN, DEPARTMENT OF GEOGRAPHY, THE
C     UNIVERSITY OF IOWA, NOVEMBER, 1974.
C     DIMENSIONING INFORMATION.
C     THE FOLLOWING ARRAY MUST BE DIMENSIONED IN THE MAIN PROGRAM AND IN
C     THE SUBROUTINE UNRAVEL.
C     LABEL(N)      STORES ONE COLUMN OF A COMPLETE DISTANCE MATRIX.
C     THE FOLLOWING ARRAYS MUST BE DIMENSIONED IN THE SUBROUTINE ONLY.
C     IPOOL(N)      STORES SUBSCRIPTS OF DISTANCES TO BE SAVED AND SORTED
C     NEXT(N)       SCRATCH VECTOR FOR OUTPUT OF DISTANCES AND SUBSCRIPTS
C     IRB(N),ILB(N) INDEX VECTORS FOR THE SOTRING PROCEUDRE.
C     N IS THE NUMBER OF ROWS (COLUMNS) IN THE COMPLETE DISTANCE MATRIX.
C     IFMT(20) STORES THE FORMAT TO BE USED IN READING ONE COLUMN OF THE
C     DISTANCE MATRIX.  ITS SIZE DOES NOT AFFECT THE SIZE OF THE MATRIX
C     THAT CAN BE PROCESSED.  HOWEVER, IT IS MACHINE-DEPENDENT AND MAY
C     HAVE TO BE CHANGED FOR MACHINES OTHER THAN THE IBM 360 AND 370.
C-----------------------------------------------------------------------
      COMMON NPUNCH,NPRINT,LABEL
      DIMENSION IFMT(20)
      DIMENSION LABEL(680)
      INTEGER*2 LABEL
      NREAD0=5
      NPRINT=6
      KPUNCH=7
      WRITE(NPRINT,4000)
C     READ CONTROL CARD AND FORMAT.
      READ (NREAD0,5000) KNODES,LAMBDA,NREAD1,NPUNCH,IFORM
       . . .
       . . .   8 lines of programs are not shown here.
       . . .
      READ (NREAD0,7000) IFMT
      WRITE(NPRINT,7100) IFMT
C     MASTER LOOP TO READ EACH COLUMN OF THE MATRIX AND CALL SUBROUTINE
C     UNRAVL.  UNRAVL WILL REFORMAT THE COLUMN AND WRITE IT OUT.
C      READ (NREAD1,7000) DUMMY
      DO 500 JDEX=1,KNODES
      READ (NREAD1,IFMT) IDZOUT,(LABEL(J), J=1,KNODES)
      CALL UNRAVL (JDEX,IDZOUT,KNODES,LAMBDA,IFORM)
  500 CONTINUE
      .     .     .     .
      .     .     .     .          approximately 122 lines of the
      .     .     .     .          program are not shown here.
      END
```

igure 5. Input Controls for the Program "UNRAVEL"

```
/GO.FT10F001 DD UNIT=DISK,DISP=(OLD,KEEP),
/ DSN=USER.A5001808.PARK.DSNIG.EUC675,
/  DCB=(RECFM=FB,BLKSIZE=7000,LRECL=70)
```

shows that the distance matrix data will be read from disc unit 10 and that its file name name is "DSNIG.EUC675"

```
/GO.FT11F001  DD  UNIT=DISK,DISP=(NEW,CATLG,DELETE),
/   DSN=USER.A5001808.PARK.UNRAV.UNFMT.NIGERIA,
/   DCB=(RECFM=VBS,LRECL=1000,BLKSIZE=1004),
/   SPACE=(TRK,(500,100),RLSE)
```

reserves space for new distance data on disc as unformatted file and names it as: "UNRAV.UNFMT.NIGERIA"

```
/GO.SYSIN  DD  *
 675  750   10   11    1
```

control information: 675 places; 750 is the largest distance to be saved; 10 is the unit number containing the distance matrix; 11 is the unit number for the new distance data(distance string and index string) created by this program. 1 means that the new distance data will be created as unformatted data. (see Hillsman, 1980, p.91)

```
48(14I5/),4I5)
/
```

describes the organization of the distance matrix data created by the program DISTANCE. In this case: 48 records each containing 14 data items followed by one with six(i.e., making total of 676 data items--1 ID and 675 distances)

Figure 6. Sample Output of the Program "UNRAVEL"

```
CREATE INDEX AND DISTANCE FILES FOR  675 NODES
ORDER DISTANCES IN INCREASING VALUES UP TO AND
INCLUDING VALUES OF 750
READ DISTANCE MATRIX FROM UNIT 10
WRITE INDEX AND DISTANCE FILES ON UNIT 11
THESE FILES WILL BE UNFORMATTED
READ DISTANCE MATRIX WITH FORMAT OF (48(14I5/),4I5)
A LISTING OF THE INDEX AND DISTANCE FILES FOLLOWS
```

This information confirms that the input instructions were correctly interpreted.

This is the first record of the index file. It describes distances from node 10001 to all other nodes within 750 distance units. These distances start at the first position and go to the 584th position. There are 584 distances in this string.

```
     1   10001       1     584       1     584
```

From 10001, the closest place is place 1 (itself) at 0 distance. From 10001, the second closest place is the 3rd node at 13 units distance. From 10001, the fifth closest place is the 49th node at 59 distance units.

```
     1     0     3    13    56    24    48    34    49    59     4    68
    51   103    50   104    57   110    11   111     2   117   113   118
     .     .     .     .
     .     .     .     .
     .     .     .     .

   425   745   545   747   543   747   430   749
```

54 lines of output are not shown here.

From 10001, the 584th place is the 430th node at 749 distance units.

This is the second record of the index file.

From ID 10002, there are 558 places within 750 distance units and these begin in the 585th position in the distance string and end in the 1142nd position.

```
     2   10002     585    1142       1     558
     2     0   113    25    .  .  .
    56   128    44   130    .  .  .
     .     .     .     .    .  .  .
     .     .     .     .    .  .  .
     .     .     .     .    .  .  .
   121   292    54   298    .  .  .
    36   310   126   314    .  .  .
```

The second closest place is 113rd place at 25 units distance. It is the 586th data pair in the "distance string". 50 lines of output are not shown here.

This is the 3rd record of the index file.

```
     3   10003    1143    1736       1     594
     3     0     1    13    48    25    56    35    47    56     4    59
    11    98    50   110    51   111    13   111    10   114   113   119
    14   128     6   128    12   129     9   130     7   130    26   156
```

Figure 7. Input File of the Program "RETRENCH"

```
/BLATRDRT JOB (15001622,50,10),'I2PARK'
*ROUTE  PRINT REMOTE2
/ EXEC FORTGCLG,REGION.GO=350K
/FORT.SYSIN DD *
      DIMENSION IWT(677), MIN(677), IDN(677), NODE(677), IDIST(677),
     * LTRY(677), NEAR(677), ELIGBL(677), KFIXED(677), DISCRD(677),
     * KANDD(677)
      DIMENSION IFMT(20), ICARD(3), INDEX(11), KTOTD(6000)
      INTEGER*2 NODE, LTRY, NEAR, IDIST, INDEX, MIN, KANDD
      INTEGER*2 INOUT, IHZERO
      LOGICAL*1 KIN, ELIGBL, KFIXED, DISCRD
      DATA ICARD /4HDECL,4HFIXE,4HDELE/
      NREAD1 = 5
      NPRINT = 6
      IZERO = 0
      IHZERO = 0
      LARGE = 32000
      WRITE (NPRINT,99999)
      READ (NREAD1,99997) N, NOCRIT, KMAX, LAMBDA, LOWLIM, INSIDE,
     * KARB, MFIX, JUNK, KPASS, NREAD2, NREAD3, NREAD4, NREAD5, NREAD9,
     * NWRIT0, NWRIT1, NWRIT2, NWRIT3
      WRITE (NPRINT,99996) N, NOCRIT, KMAX, LAMBDA
      II = 0

-----------------------------------------------------------------------
      READ THE POPULATION FILE FORMAT AND POPULATION FILE.  USE THE
      POPULATION FILE TO DECLARE NODES TO BE CANDIDATES.
-----------------------------------------------------------------------
      READ (NREAD2,99995) IFMT
      WRITE (NPRINT,99994) NREAD3
      READ (NREAD3,IFMT) (IDN(I),IWT(I),I=1,N)
      WRITE (NPRINT,99993)
      DO 10 I=1,N
         MIN(I) = LARGE
         KANDD(I) = LARGE
         ELIGBL(I) = .FALSE.
         IF (IWT(I).LT.LOWLIM) GO TO 10
         .        .        .
         .        .        .
         .        .        .

      END
```

About 420 lines of the program are not shown here.

Figure 8. Input Controls for the Program "RETRENCH"

```
//GO.FT09F001 DD UNIT=DISK,DISP=OLD,
// DSN=USER.A5001808.PARK.UNRAV.UNFMT.NIGERIA,
// DCB=(RECFM=VBS,LRECL=1000,BLKSIZE=1004)
//GO.FT10F001 DD UNIT=DISK,DISP=(NEW,CATLG,DELETE),
// DSN=USER.A5001808.FSTPSS.PARK.NIGER.DS675,
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=8000),
// SPACE=(TRK,(400,10),RLSE)
//GO.FT20F001 DD UNIT=DISK,DISP=(NEW,CATLG,DELETE),
// DSN=USER.A5001808.RETR.INDEX.PARK.KM40.UFMT,
// DCB=(RECFM=VBS,LRECL=1000,BLKSIZE=1004),
// SPACE=(TRK,(450,10),RLSE)
//GO.FT30F001 DD UNIT=DISK,DISP=(NEW,CATLG,DELETE),
// DSN=USER.A5001808.RETR.DSTFILE.PARK.KM40.UFMT,
// DCB=(RECFM=VBS,LRECL=1000,BLKSIZE=1004),
// SPACE=(TRK,(450,10),RLSE)
//GO.SYSIN DD *
```

This describes the location of the distance data created by UNRAVEL.

These are the unit numbers for writing three new data files created by RETRENCH onto the disc.
Unit 10 stores "FSTPSS"
Unit 20 stores "INDEX"
Unit 30 stores "DISTANCE"

```
  675    1  750  400        300    1  127                1      5 5 9 9  102030 6
```

control information: 675 places in the region, one class of distances will be created, largest distance in the file(created by UNRAVEL) was 750; new largest distance to be saved by this program is 400; minimum populaion size for a node to be a candidate is 300; non-candidacy is allowed for nodes outside the region; 127 arbitrary declarations for candidacy that overrule the candidacy by population above; both the read format and the population file are input from unit 5; both the index and the distance files(unformatted) are input from unit 9; 10, 20 and 30 are unit numbers for writing new data files created by this program(see above); 6 is the unit number for writing the information of fixed centers and candidates.

```
(I5,I10)
10001      2734
10002      7400
10003       225
  .    .    .
  .    .    .
  .    .    .
```

population file for the 675 nodes:
(I5,I10) is the read format for the pop. file.
The weight of node 10001 is 2734.

remainder of the 675 places ID's and populations

region declaration: 1 in col.5 means that the 5th node in the list of nodes above is within the study region.

```
11111111111111111111111111111111111111111111111111111111111111111111111111111111111
  .  .  .
  .  .  .
```

remainder of study region declaration

The following 127 arbitrary declarations for candidacy overrule any of the previous candidacy declarations:

```
DECL
1    10003    F
1    10006    F
1    10011    T
  .    .    .
  .    .    .
  .    .    .
```

DECL is the header card of the folowing declaration file.
"F" means that node 10003 is no longer a candidate.
"T" means that node 10011 is now forced to be a candidate.

remainder of candidacy declaration.

Figure 9. Sample Output of the Program "RETRENCH"

```
EDIT INDEX AND DISTANCE FILES FOR   675 NODES
INPUT INDEX FILE CONTAINS  1 CRITICAL DISTANCE CLASS(ES)
  DISTANCE CLASS(ES)--OUTPUT FILE WILL CONTAIN 1
MAXIMUM DISTANCE IN INPUT DISTANCE FILE IS       750--
  MAXIMUM IN OUTFILE WILL BE      400
READ POPULATION FILE FROM I/O UNIT  5
POPULATION FILE HAS BEEN READ
CANDIDACY
USING A POPULATION OF      300 AS A LOWER LIMIT FOR CANDIDACY,
  548 NODES ARE CANDIDATES
      0 OF THESE ARE OUTSIDE THE MAIN STUDY REGION AND
         HAVE BEEN DROPPED FROM THE LIST OF CANDIDATES
MAKE  127 ARBITRARY DECLARATIONS OF NODE CANDIDACY
THESE MAY DUPLICATE THE PROGRAMMED DECLARATIONS ABOVE
```

The above information confirms that the input instructions were correctly interpreted.

```
THE FOLLOWING   585 NODES ARE CANDIDATES FOR CENTERS
    10001      10002      10004      10005      10007      10008
      .          .          .
      .          .          .
      .          .          .
ALL OTHER NODES ARE INELIGIBLE
MAIN EDIT TO USE GENERAL MAXIMUM DISTANCE OF    400

THE FOLLOWING NODE IS A CANDIDATE
```

This is the first line of the index file.
It describes distances from node 10001 to all other nodes within 400 units of distance.
These distances start at the first position and continues to the 93rd position in the file of distance strings.

```
        1     10001       1     93     1    93
  1     0     3    13    56    24    48    34    49    59     4    68    47    69
  .     .
  .     .
  .     .
  .     .
 128   384   668   388   127   388   126   388   236   389   366   390   360   390
 375   396   122   396   238   397
CUMULATIVE NUMBER OF DISTANCES=        93
  .     .
  .     .
CUMULATIVE NUMBER OF DISTANCES=       224
```

7 lines are not shown here. From node 10001, the closest place is place 1(itself) at 0 distance.
The second closest place is the 3rd place at 13 units distance.
The 5th colsest place is the 49th node at 59 units distance.
The 93rd closest place is 238th node at 397 units distance.

18 lines for 2nd node is not shown here.

This is the 3rd record of the index file.
This shows that the 3rd place(ID 10003) is NOT eligible as a candidate.

```
        3     10003       0      0     1     0
THE FOLLOWING NODE IS A CANDIDATE
        4     10004     225    373     1   149
  4     0     5    27    48    34    45    46    46    55     3    59    47    65
  .     .     .
  .     .     .
```

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Figure 10. Input for one Analysis to Compute the p-median Solution for 11 Centers using the Teitz and Bart Heuristic Algorithm

```
//BLAQQQA6 JOB (15001808,20,,,,,0),'I4PARK',TIME=10,MSGLEVEL=(1,1)
//STEP01  EXEC PGM=NIGERIA,REGION=2000K
//STEPLIB  DD  DSN=USER.A5001622.NIGERIA,DISP=SHR
//LKED.SYSPRINT DD SYSOUT=A
//GO.FT09F001 DD UNIT=DISK,DISP=OLD,
     DSN=WYL.BLA.QQQ.NIGWTS
//GO.FT10F001 DD UNIT=DISK,DISP=OLD,
// DSN=USER.A5001808.RETR.INDEX.PARK.KM40.UFMT,
//    DCB=(RECFM=VBS,LRECL=1000,BLKSIZE=1004)
//GO.FT11F001 DD UNIT=DISK,DISP=OLD,
// DSN=USER.A5001808.RETR.DSTFILE.PARK.KM40.UFMT,
//    DCB=(RECFM=VBS,LRECL=1000,BLKSIZE=1004)
//GO.SYSIN DD *
P-MEDIAN FOR NIGERIA,11 CENTERS
```

These are unit numbers for three sets of input data files: unit 9 for weight file, unit 10 for index file, and unit 11 for distance file.

This is the title information- any title.

number of places in the distance matrix | index file of distances came from unravel or retrench | longest distance to be stored in this analysis | divide all populations by 10 | these show the storage units for the input data files

```
 675    1  400        10        10   11    9    9
```

For further information (Hillsman, 1980, P.106)

```
   0
```

This means that this problem involves no editing of distance strings (see Park and Rushton 1983, ALLOC 6B). This control item does not appear in ALLOC 6.

number of center locations to be evaluated | select the algorithm in this case the Teitz and Bart alg. | this information and the blanks in certain cases control the analysis by specifying the objective function and the material to be printed or stored (see Hillsman, 1980, pp.113-117)

```
  11    1                   1    1
```

These are the eleven place Id's that will be evaluated at the beginning then, in this case the Teitz and Bart heuristic algorithm will compute the best 11 locations to minimize average distance from the demand points to their closest center

```
  10002   10005   10032   10037   10052   20035   20054   20094
  30072   40069   40095
99999
/*
//
```

This completes the problem definition of this job.

igure 11. Sample Output for the 11 Center p-median Problem

```
PROGRAM ALLOC VI                                  I
                                                  I
WRITTEN BY  EDWARD L. HILLSMAN                    I
            DEPARTMENT OF GEOGRAPHY               I
            THE UNIVERSITY OF IOWA                I
            IOWA CITY, IOWA  52242  USA           I
                                                  I
            COPYRIGHT C 1977 EDWARD L. HILLSMAN   I
-------------------------------------------------
UN TITLE/ P-MEDIAN FOR NIGERIA,11 CENTERS         /
UMBER OF NODES IN FILES                         675
LUS ONE DUMMY NODE WITH ID OF 0
AXIMUM DISTANCE TO BE SAVED                     400
UMBER OF DISTANCE CLASSES IN INDEX FILE           1
EAD INDEX FILE FROM UNIT                         10
EAD DISTANCE FILE FROM UNIT                      11
EAD PROBLEM DEFINITIONS FROM UNIT                 5
NDEX AND DISTANCE FILES ARE UNFORMATTED
EAD WEIGHTS FORMAT FROM UNIT                      9
EAD FORMATTED WEIGHTS FROM UNIT                   9
IVIDE ALL WEIGHTS BY                             10
O FIXED CENTERS
ET SECOND FACTOR EQUAL TO ZERO
-------------------------------------------------
UMBER OF DISTANCES STORED IS                 202828
AXIMUM PERMITTED IS                          210000
ENGTH OF LONGEST STRING IS                      518
UMBER OF NODES INSIDE STUDY REGION IS           675
OTAL WEIGHT AFTER SCALING IS                 101559
OTAL INSIDE IS                               101559
ROVIDE INFEASIBLE SERVICE AT A COST OF      1164083
-------------------------------------------------
IST OF NODE ID NUMBERS AND POPULATIONS

10001 IDIYA      273    10002 IMALA      740    10003 KETU        23
10005            142    10006 GBOGILAW    25    10007 IKEREKUO    59
10009 OKEODO     139    10010 OLORUNDA   133    10011 AKINIYI      7
10013 OCOWOYIN    93    10014 KESAM       98    10015 ILUGUN      47
 .    .    .
 .    .    .
 .    .    .
```

This information confirms that the input instructions were correctly interpreted.

The remainder of list of node ID's, names and populations

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Figure 12.

P-MEDIAN FOR NIGERIA,11 CENTERS
PROBLEM NUMBER 1

LOCATE 11 CENTERS

MALG	ICON	MALG2	KRIT	NMAP	MMAP	MACH
1	0	0	0	1	1	0

LIST OF CENTERS

CENTER(ID & NAME)	WT(CENTER	OUTSIDE	TOTAL)	WT*DISTANCE	COST IF DROPPED
40069 OKENLA	13	8504	8517	113479	39286
. . .					
. . .	remaining 9 centers				
. . .					
40095 IFO	1830	15513	17343	197350	112045

FOR THE LIST OF CENTERS ABOVE:
TOTAL ALLOCATED WEIGHTED DISTANCE IS 809110
AVERAGE DISTANCE OF ALLOCATED PLACES TO NEAREST CENTERS IS 7.967
TOTAL UNALLOCATED POPULATION IS 0

WEIGHT:	
TOTAL=	101559
CENTERS=	33976
OUTSIDE CENTERS=	67583
% OUTSIDE=	66.55
AV DISTANCE OF OUTSIDE=	11.97

LIST OF NODES

NODE		CENTER	WEIGHT	DIST	NODE		CENTER	WEIGHT	DIST
II 10025	10052	ABEOKUTA	47	4	II 10026	10032	ISAGA	32	8
II 10028	10032	ISAGA	22	6	II 10029	10032	ISAGA	32	5
II 10031	10032	ISAGA	470	5	II 10032	10032	ISAGA	667	0
II 10034	10037	KUTA	14	2	II 10035	10037	KUTA	11	4
II 10037	10037	KUTA	23	0	II 10038	10037	KUTA	8	3
II 10040	10037	KUTA	35	3	II 10041	10037	KUTA	157	5
. . .									
. . .	the remainder of list of nodes in the starting solution								
. . .									

LIST OF TRADE AREAS (NODE ID, WEIGHT, AND DISTANCE TO CENTER)

10002	740	0	20055	57	2	10050	9	3
. . .								
. . .	the remainder of nodes assigned to the center 10002							
10058	443	16	30131	47	19			
10005	142	0	10004	43	2	10045	47	3
. . .								
. . .	the remainder of nodes assigned to center 10005							
10010	133	4	10012	8	5	10003	23	8
. . .								
. . .	the remaining 9 groups of trade areas							
. . .	143 lines are not shown here.							

gure 13.

```
UMMARY STATISTICS
OTAL ALLOCATED WEIGHTED DISTANCE IS                                  809110
VERAGE DISTANCE OF ALLOCATED PLACES TO NEAREST CENTERS IS             7.967
OTAL UNALLOCATED POPULATION IS                                            0
VER ENTIRE PROBLEM, MAXIMUM DISTANCE TRAVELED IS        39
 FROM NODE    20001 TO CENTER    20035
NSIDE STUDY REGION, MAXIMUM DISTANCE TRAVELED IS        39
 FROM NODE    20001 TO CENTER    20035
OST EXPENDABLE CENTER IS    10032
HICH WOULD INCREASE THE OBJECTIVE FUNCTION BY      5816
   IF DROPPED WITHOUT REPLACEMENT
-------------------------------------------------------------------------------

TART TEITZ AND BART ALGORITHM
            COST IF
 OLD CENTER DROPPED   NEW CENTER    TOTAL COST    NET CHANGE   PERCENT CHANGE
   10032      5816       10001        808426         684          0.0845
   10005      7612       10007        805956        2470          0.3055
   10007     10082       10009        805540         416          0.0516
   10009     10498       10016        804592         948          0.1177
   40098     82221       40237        601064        8829          1.4476
-----------------------------------------------------------------END CYCLE  1

HANGES = 60
   10002    202253       10001        599804        1260          0.2096
     .        .        .
     .        .        .   17 lines are not shown here.
     .        .        .
   20125     72432       20132        575211        1485          0.2575
-----------------------------------------------------------------END CYCLE  2

HANGES = 19
-----------------------------------------------------------------END CYCLE  3

HANGES =  0
ND TEITZ AND BART ALGORITHM                          WEIGHT    AVERAGE
IST OF CENTERS                                        *        DISTANCE          COST IF
CENTER(ID & NAME)   WT(CENTER  OUTSIDE  TOTAL)  DISTANCE  (ALL & OUTSIDE)  DROPPED
-------------------------------------------------------------------------------
 10010 OLORUNDA       133       4264     4397    51888    11.80    12.17    1208048
 20132 TOSUN          375       6173     6548    54183     8.27     8.78      73917
     . . .
     . . .   9 lines are not shown here.
     . . .
 40237 AIYEDE          47       9181     9228    64782     7.02     7.06      90755
OR THE LIST OF CENTERS ABOVE:
OTAL ALLOCATED WEIGHTED DISTANCE IS                                  575211
VERAGE DISTANCE OF ALLOCATED PLACES TO NEAREST CENTERS IS             5.664
OTAL UNALLOCATED POPULATION IS                                            0
 WEIGHT:        TOTAL=      101559
              CENTERS=       33303
      OUTSIDE CENTERS=       68256
            % OUTSIDE=       67.21
V DISTANCE OF OUTSIDE=        8.43
```

Figure 14.

```
LIST OF NODES

      NODE       CENTER   WEIGHT  DIST          NODE       CENTER   WEIGHT  DIST
DIST

II 10001  10010 OLORUNDA    273     12  II 10002  10010 OLORUNDA    740     15
II 10004  10010 OLORUNDA     43      6  II 10005  10010 OLORUNDA    142      4
   .     .     .
   .     .     .  the remainder of list of nodes in the optimal solution
   .     .     .
II 40257  10052 ABEOKUTA     23     19  II 40258  10052 ABEOKUTA     46     19
II 40260  10052 ABEOKUTA     47     19  II 40261  10010 OLORUNDA     14     20


LIST OF TRADE AREAS (NODE ID, WEIGHT, AND DISTANCE TO CENTER,
  WHICH IS FIRST ID IN EACH AREA)
  10010  133    0        10012    8    1        10009  139    2    2
  .     .     .  the remainder of nodes assigned to center 10010
  .     .     .  41 nodes were assigned to this center including itself
  .     .     .
  10002  740    15       10050    9   16        10051    5   17   18
  10058  443    23
  41

  .     .     .  remaining 10 groups of trade areas
  .     .     .  About 150 lines were not shown here
  .     .     .


SUMMARY STATISTICS
TOTAL ALLOCATED WEIGHTED DISTANCE IS                          575211
AVERAGE DISTANCE OF ALLOCATED PLACES TO NEAREST CENTERS IS      5.664
TOTAL UNALLOCATED POPULATION IS                                     0
OVER ENTIRE PROBLEM, MAXIMUM DISTANCE TRAVELED IS        23
   FROM NODE    10058 TO CENTER    10010
INSIDE STUDY REGION, MAXIMUM DISTANCE TRAVELED IS        23
   FROM NODE    10058 TO CENTER    10010
AVERAGE VALUE OF SECOND FACTOR IS    0.0
MOST EXPENDABLE CENTER IS    20009
WHICH WOULD INCREASE THE OBJECTIVE FUNCTION BY     42663
   IF DROPPED WITHOUT REPLACEMENT
PERCENT CHANGE IN OBJECTIVE FUNCTION FROM INITIAL LIST  OF CENTERS IS   28.9082
                                     FROM LAST PRINTING IS              28.9082
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
```

Figure 15.

COMPARISON OF CENTERS BETWEEN BEGINNING AND END SOLUTIONS>>

NEW CENTERS(CENTERS NOT IN THE BEGINNING SET)

ID	NAME	WT(CENTER	OUTSIDE	TOTAL)	WT*DIST	NODES	AV DIST(ALL	& OUTSIDE)
10010	OLORUNDA	133	4264	4397	51888	41	11.80	12.17
. . .								
. . .	7 lines are not shown here.							
. . .								
40237	AIYEDE	47	9181	9228	64782	89	7.02	7.06
TOTAL	9 CENTERS	3805	50561	54366	403373	515		
AVERAGE		422.8	5617.9	6040.7	44819.2	57.2	7.42	7.98
AV WT/NODE OUTSIDE			99.9					

REMAINING CENTERS(CENTERS BOTH IN BEGINNING AND END SETS)

ID	NAME	WT(CENTER	OUTSIDE	TOTAL)	WT*DIST	NODES	AV DIST(A	& O)
10052	ABEOKUTA	29175	6128	35303	59115	60	1.67	9.65
20054	AROSA	323	11567	11890	112723	100	9.48	9.75
TOTAL	2 CENTERS	29498	17695	47193	171838	160		
AVERAGE		14749.0	8847.5	23596.5	85919.0	80.0	3.64	9.71
AV WT/NODE OUTSIDE			112.0					

**** BEGINNING SET ****

	WT(OUTSIDE	TOTAL)	WT*DIST	NODES	AV DIST(A	& O)
	2910	32085	18214	23	0.57	6.26
	7927	8250	76578	76	9.28	9.66
TOTAL	10837	40335	94792	99		
AVERAGE	5418.5	20167.5	47396.0	49.5	2.35	5.36

OLD CENTERS(CENTERS NOT IN THE END SET)

ID	NAME	WT(CENTER	OUTSIDE	TOTAL)	WT*DIST	NODES	AV DIST(ALL	& OUTSIDE)
10002	IMALA	740	718	1458	10066	7	6.90	14.02
. . .								
. . .	7 lines are not shown here.							
. . .								
40095	IFO	1830	15513	17343	197350	154	11.38	12.72
TOTAL	9 CENTERS	4478	56746	61224	714318	576		
AVERAGE		497.6	6305.1	6802.7	79368.6	64.0	11.67	12.59
AV WT/NODE OUTSIDE			100.1					

Figure 16.

<<COMPARISON OF NODE ASSIGNMENTS>>

NODE		WEIGHT	CENTER		DISTANCE GAIN/LOSS				WT*DIST GAIN/LOSS		
ID	NAME		BEGIN	END	BEGIN		END		BEGIN	END	
10001	IDIYA	273	10005	10010	1	9	12	-3	2457	3276	-819
10002	IMALA	740	10002	10010	1	0	15	-15	0	11100	-11100
10003	KETU	23	10005	10010	1	8	11	-3	184	253	-69
10004	IMALAW	43	10005	10010	1	2	6	-4	86	258	-172
10005		142	10005	10010	1	0	4	-4	0	568	-568
10006	GBOGILAW	25	10005	10010	1	4	4	0	100	100	0
NODE	10006 IS ASSIGNED TO DIFFERENT CENTER BUT HAS SAME DISTANCE.										
10007	IKEREKUO	59	10005	10010	1	4	3	1	236	177	59

. . .
. . . the remainder of node assignment comparison
. . . About 710 lines were not shown here.

<<THE SPATIAL ACCESSIBILITY OF PEOPLE AND PLACES FOR THE BEGINNING AND END SET OF CENTERS>>

	CHANGES IN SPATIAL ACCESSIBILITY		
	SAME	CLOSER	FARTHER
NUMBER OF PEOPLE	45406	35397	20756
PERCENT OF PEOPLE	44.71	34.85	20.44
NUMBER OF PLACES	147	342	186
PERCENT OF PLACES	21.78	50.67	27.56

<<COMPARISON OF THE SPATIAL ACCESSIBILITY BETWEEN THE BEGINNING AND ENDING SET OF CENTERS>>

	SAME	CLOSER	FARTHER
AVERAGE DISTANCE IN THE BEGINNING	3.00	15.12	5.11
AVERAGE DISTANCE AT THE END	3.00	5.86	9.49
% RATIO OF DISTANCES(END/BEGIN)	100.00	38.77	185.56
AVERAGE NO. OF PERSONS IN PLACES	308.88	103.50	111.59

CENTER LOCATIONS AT BEGINNING OF PROBLEM

10002	10005	10032	10037	10052	20035	20054	20094
30072	40069	40095					

LOCATIONS OF CENTERS AT END OF ALGORITHM

10010	20132	20009	40143	10052	20041	20054	40228
20100	40033	40237					

END OF PROBLEM
OBJECTIVE FUNCTION AT START AND END
1 809110 575211

References.

Banerji, S. and Fisher, H.B. 1974a. Hierarchical location analysis for area planning in rural India. Papers of the Regional Science Association 33: 177-94.

Banerji, S. and Fisher, H.B. 1974b. Spatial analysis for integrated area planning in India. Urban and Rural Planning Thought (India) 17,1: 1-46.

Beaumont, J.R. 1980. Spatial interaction models and the location-allocation problem. Journal of Regional Science 20: 37-50.

Bennett, Vivienne L., Eaton, David J. and Church, Richard L. 1982. Selecting sites for rural health workers. Social Science and Medicine 16: 63-72.

Bose, A., and Desai, P.B. 1983. Studies in Social Dynamics of Primary Health Care. Delhi: Hindustan Publishing Corp.

Brill, E.D. Jr. 1979. The use of optimization models in public-sector planning. Management Science 25,5: 413-22.

Casillas, P. 1983. Data aggregation and the p-median problem. Discussion Paper #35, Department of Geography, The University of Iowa, Iowa City, Iowa. 28pp.

Church, R. and ReVelle, C. 1974. The maximal covering location problem. Papers of the Regional Science Association 32: 101-18.

Church, R. and ReVelle, C. 1976. Theoretical and computational links between the p-median and the maximal covering location problems. Geographical Analysis 8: 406-15.

Cornuejols, G., Fisher, M.L., and Nemhauser, G.L. 1977. Location of bank accounts to optimize float. Management Science 23: 789-810.

Dokmeci, F. 1973. An optimization model for a hierarchical spatial system. Journal of Regional Science 13,3: 439-51.

Dokmeci, F. 1977 A quantitative model to plan regional health facility systems. Management Science 24,4: 411-19.

Eaton, D.J., Church, R.L., Bennett, V.L., Hamon, B.L., and Lopez, L.G.V. 1981. On deployment of health resources in rural Valle del Cauca, Columbia. TIMS Studies in the Management Sciences 17: 331-59.

Eaton, D., ReVelle, C., and Church, R. 1977. Location Analysis: A new tool for health planners. Washington D.C.: U.S. Agency for International Development, Methodological Working Doc. No. 53, mimeographed.

Erlenkotter, D. 1978. A dual-based procedure for uncapacitated facility location. Operations Research. 26: 992-1009.

Evans, Hugh 1982. Urban Functions in Rural Development: The case of the Potosi Region in Bolivia, Part I and II. Washington D.C.: United States Agency for International Development, Bureau for Science and Technology, Office of Multisectoral Development, Regional and Rural Development Division.

Fisher, H. B., and Rushton, G. 1977. Integrated rural area planning in India: Experiences of the pilot research project in growth centres--1969-1974. In Man, Culture, and Settlement, eds. R.C. Eidt, K.N. Singh, and R.P.B. Singh, pp. 342-62. New Delhi, India: Kalyani Publishers.

Fisher, H.B., and Rushton, G. 1979. Spatial efficiency of service locations and the regional development process. Papers of the Regional Science Association 42: 83-97.

Ginsburgh, V. and Hansen, P. 1974. Procedures for the reduction of errors in road network data. Operational Research Quarterly 25: 321.

Golladay, F., and Liesen, B. 1980. Health Problems and Policies in the Developing Countries. Washington D.C.: World Bank Staff Working Paper, No. 421.

Goodchild, M.F. 1979. The aggregation problem in location-allocation. Geographical Analysis 11: 240-55.

Goodchild, M.F., and Noronha, V.T. 1983. Location-Allocation for Small Computers. Iowa City, Iowa: Department of Geography, The University of Iowa, Monograph 8.

Gould, W.T.S. 1978. Guidelines for school location planning. Washington D.C.: The World Bank, Staff Working Paper No. 308.

Government of India. 1980. India: A Reference Manual. New Delhi: Ministry of Information and Broadcasting.

Grove, D., and Hussar, L. 1964. The Towns of Ghana: The Role of Service Centres in Regional Planning. Accra: Ghana University Press.

Hakimi, S.L. 1964. Optimum locations of switching centers and absolute centers and medians of a graph. Operations Research 12: 450-59.

Hallak, Jacques. 1977. Planning the Location of Schools. New York: UNESCO, International Institute for Educational Planning.

Hansen, P., Peeters, D., and Thisse, J.-F. 1983. Public facility location models: A selective survey. In Locational Analysis of Public Facilities, eds. J.F. Thisse and H.G. Zoller, pp. 223-62. New York: North-Holland Pub. Co.

Harvey, M.E., Hung, Ming-Shing, and Brown, J.R. 1974. The application of a p-median algorithm to the identification of nodal hierarchies and growth centers. Economic Geography 50,3: 187-202.

Hillsman, E.L. 1980. Heuristic Solutions to Location-Allocation Problems: A User's Guide to ALLOC IV, V, and VI. Iowa City, Iowa: Geography Department, University of Iowa, Monograph 7.

Hillsman, E.L. 1983. The p-median structure as a unified linear model for location-allocation analysis. forthcoming, Environment and Planning A.

Hillsman, E.L., and Dwarakinath, S. 1984. A Computerized Location-Allocation System. forthcoming, Iowa City, Iowa: Department of Geography, The University of Iowa, Monograph 9.

Hillsman, E.L. and Rhoda, R. 1978. Errors in measuring distances from populations to service centers. Annals of Regional Science 12: 74-88.

Hillsman, E.L., and Rushton, G. 1975. The p-median problem with maximum distance constraints: A comment. Geographical Analysis 7: 85-90.

Hodgart, R.L. 1978. Optimizing access to public services: A review of problems, models and methods of locating central facilities. Progress in Human Geography 2: 17-48.

Hodgson, M.J. 1978. Toward more realistic allocation in location-allocation models: an interaction approach. Environment and Planning A. 10: 1273-86.

Horowitz, J. 1981. Sampling, specification and data errors in probabilistic discrete choice models, in D.A. Hensher and L.W. Johnson, Applied Discrete Choice Modeling, (New York, J.Wiley and Sons), pp.417-35.

India, Ministry of Health 1969. Report of the Rural-Urban Relationship Committee. Delhi: Manager of Publications.

India, Planning Commission 1970. Fourth Five Year Plan. Delhi: Manager of Publications.

Indian Council of Social Science Research and the Indian Council of

Medical Research- Indian Institute of Education. 1981. Health for All: An Alternative Strategy. New Delhi: ICSSR, Report of a Study Group.

International Institute for Educational Planning. 1980a. Note on IIEP experience in school mapping. Paris: UNESCO, IIEP, March 24, (IIEP/Prg./FC/80.069), mimeographed.

International Institute for Educational Planning. 1980b. Note on microplanning. Paris: UNESCO, IIEP, July 1, (IIEP/S.63/Basic Document), mimeographed.

International Institute for Educational Planning. 1981. IIEP programme on microplanning of Education. Paria: UNESCO, IIEP, May 29, (IIEP/Prg.FC/81.100), mimeographed.

Johnson, E.A.J. 1970. The Organization of Space in Developing Countries. Cambridge, Mass.: Harvard University Press.

Johnson, E.A.J. 1966. Market Towns and Spatial Development in India. New Delhi: National Council of Applied Economic Research.

Kolesar, Peter J. 1979. Travel time and travel distance models. In Fire Department Deployment Analysis, eds. W.W. Walker, J.M. Chaiken, and E.J. Ignall, pp. 157-201. New York: North-Holland Pub. Co.

Kuehn, A.A., and Hamburger, M.J. 1963. A heuristic program for locating warehouses. Management Science 9: 643-66.

Kusumadewa, A.L., Fisher, H.B. and Wiyono, H. 1977. Analisa lokasi untuk perencanaan pusatpusat pelayanan. Prisma (Indonesia) 11: 13-30.

Larson, R.C. and Odoni, A.R. 1981. Urban Operations Research. (Englewood Cliffs, New Jersey), pp. 364-69.

Leamer, E.E. 1968. Locational equilibria. Journal of Regional Science 8,2: 229-42.

Leonardi, G. 1982. Public facility location, in G. Leonardi (ed) Public Facility Location: Issues and Approaches. Laxenburg, Austria: International Institute for Applied Systems Analysis, (Reprinted from Sistemi Urbani, Vol. 3, 1981). pp. 293-97.

Levy, J. 1967. An extended theorem for location on a network. Operational Research Quarterly 18: 433-42.

Losch, A. 1954. The Economics of Location. (transl. W.H. Woglom and W.F. Stolper), New Haven, Conn.: Yale University Press.

Love, R.F., and Morris, J.G. 1972. Modelling inter-city road distances by mathematical functions. Operational Research Quarterly 23:

61-71.

Love, R.F., and Morris, J.G. 1979. Mathematical models of road travel distances. Management Science 25: 130-39.

Maranzana, F. 1964. On the location of supply points to minimize transport costs. Operations Research Quarterly 15: 261-70.

Mehretu, A., Wittick, R.I., and Pigozzi, B.W. 1983. Spatial design for basic needs in eastern Upper Volta. forthcoming, Journal of Developing Areas.

Mirchandani, P. and Francis, R. (eds.) 1984. Discrete Location Theory. forthcoming, J. Wiley & Sons, New York.

Moore, G.C., and ReVelle, C. 1982. The hierarchical service location problem. Management Science 28,7: 775-80.

Moore, G.C. 1982. The Spatial Organiz of Health Services. Moore, Oklahoma: G.C. Moore, mimeographed.

Morley, D., Rohde, J.E., and Williams, G. eds. 1983. Practising Health for All. New York: Oxford University Press.

Narula, S.C. and Ogbu, U.I. 1979. An hierarchal location-allocation problem. Omega 7,2: 137-43.

NCERT. 1970. Education and National Development: Report of the Education Commission 1964-66. New Delhi: National Council of Educational Research and Training.

NCERT. 1978. Fourth All India Educational Survey: Guidelines for Survey Officers. New Delhi: National Council of Educational Research and Training.

Park, Soobyong. 1983. Aggregation effects and disaggregation of demand in locational analysis. Discussion Paper # 36, Department of Geography, The University of Iowa, Iowa City, Iowa.

Patel, N.R. 1979. Locating rural social service centers in India. Management Science 25,1: 22-30.

ReVelle, C., Bigman, D., Schilling, D., Cohon, J., and Church, R. 1977. Facility location: a review of context-free and EMS models. Health Services Research 12,2: 129-45.

ReVelle, C., and Church, R. 1977. A spatial model for the location construct of Teitz. Papers of the Regional Science Association 39: 129-35.

ReVelle, C., Cohon, J., and Shobrys, D. 1981. Multiple objective

facility location. Sistemi Urbani 3: 319-43.

ReVelle, C. and Swain, R. 1970 Central facilities location. Geographical Analysis 2: 30-42.

Robinson, V.B. 1983a. Urban Data Management Software (U.D.M.S.) Package-- Programme Listings. Nairobi, Kenya: United Nations Centre for Human Settlements (HABITAT).

Robinson, V.B. 1983b. Urban Data Management Software (U.D.M.S.) Package--User's Manual. Nairobi, Kenya: United Nations Centre for Human Settlements (HABITAT).

Rondinelli, D.A. 1979. Applied policy analysis for integrated regional development planning in the Philippines. Third World Planning Review 1: 150-78.

Rondinelli, D.A. 1980. Spatial analysis for regional development: A case study in the Bicol River basin of the Philippines. Tokyo: United Nations University, Natural Resources Programme, Resource Systems, Theory and Methodology Technical Papers, No. 1.

Rondinelli, D.A. and Evans, H. 1983. Integrated regional development planning: linking urban centres and rural areas in Bolivia. World Development 2,1: 31-53.

Rondinelli, D.A. and Ruddle, K. 1978. Urbanization and Rural Development: A Spatial Policy for Equitable Growth. New York: Praeger.

Rosing, K. Hillsman, E.L. and Rosing-Vogelaar, H. 1979. A note comparing optimal and heuristic solutions to the p-median problem. Geographical Analysis 11: 373-80.

Rosing, K. Hillsman, E.L. and Rosing-Vogelaar, H. 1979. The robustness of two common heuristics for the p-median problem. Environment and Planning A 11: 373-80.

Roy, P., and Patil, B.R., eds. 1977. Manual for Block Level Planning. Delhi, India: The Macmillan Co. Ltd.

Rushton, G. 1971. Postulates of central place theory and the properties of central place systems. Geographical Analysis 3: 140-56.

Rushton, G. 1983. Costs and benefits of a locational constraint designed to ensure geographical accessibility of a rural population to health services. Iowa City, Iowa: Institute of Urban and Regional Research, The University of Iowa, Research Report # 30, pp.1-7.

Rushton, G., Goodchild, M.F. and Ostresh, Jr., L.M. eds. 1973. Computer Programs for Location-Allocation Problems. Iowa City, Iowa:

Department of Geography, The University of Iowa, monograph 6.

Rushton, G. and Krishnamurthi, A. 1983. Locational efficiency of health care services in an Indian District. Paper delivered at the Meetings of The Association of American Geographers, Denver.

Schilling, D.A., McGarity, A., and ReVelle, C. 1982. Hidden attributes and the display of information in multiobjective analysis. Management Science 28,3: 236-42.

Scott, A.J. 1971. Combinatorial Programming, Spatial Analysis and Planning. London: Methuen.

Shah, S.M. 1974. Growth centers as a strategy for rural development: India experience. Economic Development and Cultural Change 22,2: 215-28.

Stock, R. 1983. Distance and the utilization of health facilities in rural Nigeria. Social Science and Medicine 17: 563-70.

Teitz, M.B. 1968. Toward a theory of urban public facility location. Papers of the Regional Science Association 21: 35-51.

Teitz, M.B. and Bart, P. 1968. Heuristic Methods for estimating the generalized vertex median of a weighted graph. Operations Research 16: 955-61.

Tewari, V.K. and Jena, S. 1983. On the methodology of locating school education facilities in rural India. Bangalore, India: Indian Institute of Management, mimeographed.

Timbers, J.A. 1967. Route factors in road networks. Traffic Engineering and Control. 9: 392-94.

Tobler, W.R. 1979. Smooth pychnophylactic interpolation for geographical regions. Journal of the American Statistical Association 74: 519-30.

Tornquist, G., et.al. 1971. Multiple Location Analysis. Lund Studies in Geography, Ser.C. General, No. 12. (Lund:C.W.K. Gleerup).

World Bank. 1980a. Education Sector Policy Paper. Washington D.C.: World Bank (Third Edition).

World Bank. 1980b. Health Sector Paper. Washington D.C.: World Bank.

WHO-UNICEF. 1978. Primary Health Care--Report of the International Conference on Primary Health Care, Alma Ata, U.S.S.R. Geneva: World Health Organization.