The Location of Health Centers in a Rural Region using a Decision Support System: A Zambian Case Study

Bryan H. Massam
York University, Canada*

Jacek Malczewski
University of Western Ontario, Canada**

Many researchers have argued that the provision of high-quality health care in rural areas serves as a vital component in successful development planning. A key element of rural health care planning relates to the search for appropriate locations for health centers. Alternate location patterns must be evaluated and assessed, and definitions of goals and objectives are required. This paper offers a test of a computer-based decision support system (DSS) called DINAS (Dynamic Interactive Network Analysis System) for tackling the problem of comparing alternate locations for health care centers, with a view to identifying the most appropriate location for a center. Prior to discussing the application of DINAS to a specific location problem in two districts in Zambia (Mpika and Sesheke), general comments on DSS are provided. In Mpika seven alternate locations are evaluated, using six criteria relating to accessibility and potential utilization patterns. The same set of criteria is used for the Sesheke District data set, and ten locations are considered. The site selection problem had to be stated in a specific way in order that DINAS could be used, since this DSS had traditionally been applied to location-allocation problems.

The results generated by DINAS are compared to those provided by the application of concordance analysis. Finally, it is suggested that a DSS, such as DINAS, can contribute to improved planning.

A number of authors, such as Bennet et al. (1982), Fisher and Rushton (1979), Lonsdale and Enyedi (1984), and Wanmali (1983), have identified as a key element in successful regional development planning the need to find appropriate locations for facilities providing a wide range of services. One of the most important services which is needed in order to improve living standards and economic and social development

* Department of Geography, York University, North York, Ontario, Canada.
** Department of Geography, University of Western Ontario, London, Ontario, Canada.

Geography Research Forum • Vol. 11 • 1991:1-24

relates to the provision of health care. Improvements to health can have a direct positive effect on productivity as well as well-being, personal satisfaction and enjoyment of life. While significant improvements can result most effectively from investments in better water and sewage schemes and modifications to food supplies and diet (Massam and Askew, 1984) the 1978 Declaration of Alma Ata, which was sponsored by UNESCO and WHO, clearly states that preventative services provided from primary health care (PHC) centers, rather than curative ones, is the appropriate strategy to improve the human condition, especially in rural areas of Third World countries. The PHC emphasizes non-medical components for health care, para-professional as well as medical personnel, and places a high priority on community scale facilities as the first level of a hierarchical referral system. The decentralization and extension of health care delivery systems to the community level is thus the major strategy for improving the accessibility to health facilities. A clear geographical problem emerges, namely: Given a set of feasible locations for a health center, find the best location.

In order to tackle this very general location choice problem it is necessary to provide clear statements first, about the optional locations, second the attributes of each option and third, the definition of "best" which is to be adopted for a particular problem.

In this paper we wish to consider the use of a computer-based Decision Support System (DSS) called DINAS (Dynamic Interactive Network Analysis System) for tackling this type of location problem. This is the first time that DINAS has been applied to a problem of this nature.

The introductory section of the paper will elaborate on the general location problem, while in section two, we will define and provide comments on Decision Support Systems. In section three, details of DINAS are given as well as a summary of the adjustments that have been made to tackle the location problem posed earlier. Section four provides an application of DINAS to a set of empirical data for two regions in Zambia in which the problem is to select sites for new health care facilities, given a set of feasible alternatives. The data are taken from an earlier paper by Massam et al. (1986) in which a multi-criteria method based on concordance analysis was used to classify alternative locations with a view to identifying their relative attractiveness as sites for health centers. In a further paper by Massam (1988a) the formal concordance model was compared to intuitive approaches of experienced and inexperienced health care planners. Among the conclusions it was noted that successful plan evaluation, implementation and monitoring can involve formal methods of the multi-criteria variety, however it is vital that such methods be used interactively by those who take decisions and are responsible for the outcomes. To this end DSS's are growing in importance (Massam and Malczewski, 1990). The view we espouse accords with this planning objective of greater accountability while using modern analytical techniques to handle data.

The general location problem that has been outlined above is embraced by a generic planning problem (GPP) which has been formulated by Massam (1988b). The GPP is stated as: "Given a set of M plans, and for each an evaluation on a set of N criteria, for a set of G interest groups, classify the M plans in such a way as to identify their relative attractiveness so that agreement among the interest groups is maximized" (Massam, 1988b, 19).

A review of five major categories of multi-criteria decision-making (MCDM) techniques which can be used to tackle this problem, is provided in Massam (1988b) and an overview of some interdisciplinary approaches to the problem is given in Massam (1988c).

The emphasis in these documents focuses on the need to involve in the evaluation part of the problem those who are responsible for taking decisions. While the evaluation can rely on the use of rigorous numerical, analytical and statistical procedures, it is most important that those who use the results of such work believe that the procedures offer credible results and that, if necessary, the procedures can be scrutinized publicly and their internal logic explained so that the analysis can be repeated to yield consistent results. There is a need to provide clear explanations of the evaluation process as a critical step in the improvement of the quality of planning. We subscribe to this view and argue that potentially DSS can help to inform public debate in a responsible fashion to help in the management of complex location problems of the type we address here. While operations research tools can often provide specific solutions to well-posed problems, the complexity of most practical location problems with the uncertainties surrounding the definitions of the options, the evaluation criteria, the impact scores and the preferences of the interest groups demands that a dynamic interactive framework be found which links information and analysis to responsible authoritative decision-making. To this end we suggest that DSS have an important role and in this paper we wish to explore this possibility. The final section of the paper will offer our opinions on the application of DINAS to the health center location problem in Zambia and more generally we will comment on the utility of the procedure for tackling a variety of location problems we have classified under the GPP outlined earlier.

It should be noted that while the case study addressed in this paper deals with a location problem in a developing country, there are many practical location problems in developed countries which need to be tackled. Typically these problems include the search for locations for the provision of public or private goods and services, for example retail outlets, health care, education as well as emergency services and noxious facilities, such as power stations and waste disposal dumps. With respect to both categories—public or private—it is clear that planners, bureaucrats, politicians and the public are anxious that academics provide assistance in the development of techniques and planning processes which improve accountability, allow different perspectives of interest groups to be considered and provide analyses which are logically consistent and can be scrutinized publicly. With all these points in mind we suggest that computer-based Decision Support Systems, such as the one used in this paper, have a useful role to play in the planning and management of built environments in all countries, developed and developing, and all regions, rural and urban. DSS should have a useful role to play in the planning of delivery systems for public and private goods (Massam, 1975; 1980; Jones and Simmons, 1987).

DECISION SUPPORT SYSTEMS (DSS)

It is not our purpose to describe in detail the managerial support systems (MSS) which are available to tackle decision-making problems. Typically such systems do not specifically consider spatial aspects of planning problems. A useful review of MSS as a category of planning technique which embraces DSS is provided by Taylor and Taylor (1987). This section provides a selective overview of DSS as used for locational planning to complement the excellent review by Armstrong et al.(1986) and Densham and Rushton (1987). These authors focus on spatial planning problems and hence use the term Spatial Decision Support System (SDSS) to characterize their work. In this paper we wish to focus on a class of SDSS that is based on an interactive approach to the resolution of a site selection problem.

In its broadest sense every computer-based system which processes a set of information can be classified as a DSS. The purpose of such a system is to help managers to achieve "better" decisions. By better we suggest that decisions could be reached faster, probably using extensive data sets and within a framework which allows sensitivity tests, and most particularly so that results can be scrutinized and repeated. The essence is to avoid the "black box" style of plan and policy evaluation and selection. It should be emphasized that a DSS does not replace the judgements of decision-makers, rather it provides a computer-based planning tool which seeks to achieve a higher effectiveness of decision-making. This point is discussed in Keen and Scott-Morton (1978).

To improve the effectiveness of decision-making one should incorporate two elements into the planning process: first, a substantive model of the decision situation or a decision-making model which is formulated by a team of analysts or a single analyst; and second, the participation of the decision-makers, which we can refer to as the interest groups, in the solution of a planning problem; they provide the judgemental information, in the form of preferences, about the significance of impacts, which cannot be expressed a priori in a formal language and are therefore excluded from the analyst's initial model. It is argued that these two elements are the integral parts of any planning process.

In this context, it is important to be aware that the concept of rationality underlies all decision-making or optimization model-building. It is assumed that there is a decision-maker or a group of decision-makers who behave according to coherent and optimal rules (Colerni, 1987). Consequently, an optimization model could be used for the solution of well-structured planning problems. In reality, however, the analyst almost always faces a semi-structured or ill-structured problem. Usually, the analyst's model approximates the real-word planning situation. In particular, the less tangible aspects of the planning problem are often neglected. It seems that the best way to incorporate these aspects of the planning problem is to involve in the planning process the decision-makers who are ultimately responsible for implementation of a plan and those who are accountable to a defined constituency (Day and Klein, 1987). This can be done by means of a suitable DSS, which incorporates both the optimization model formalized by the analysts and the judgemental aspects of the problem that can be supplied to the system by the decision-makers.

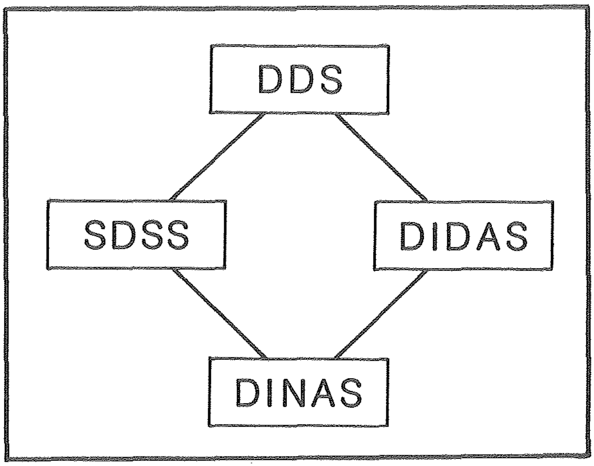
There are many computer-based systems that can be used as a DSS for locational planning. One of the most popular and best-known is the urban data management software (UDMS) package, that has been developed in the United Nations Center for Human Settlements (Robinson, 1983; Robinson and Coiner, 1986). This software enables, inter alia, solution of a semi-structured location problem and at the same time it allows the decision-makers to be involved in the process of the problem solution. Furthermore, UDMS can be used to solve multi-objective location problems situated in a fairly complex decision-making environment.

Horn et al. (1988) have presented a prototype of a system called the Interactive Territory Assignment (ITA) package. Although this system has been primarily used to plan administrative districts, it can be also used to solve locational planning problems. Since ITA enables the solution of a locational model with the participation of decision-makers it can be considered as a DSS.

In the 1980s, a family of DSS called Dynamic Interactive Decision Analysis and Support (DIDAS) was developed at the International Institute for Applied Systems Analysis (IIASA) (Lewandowski and Wierzbicki, 1987). In contrast to the two software packages described above, all DIDAS systems can be considered as purpose-made DSS. The objective of the systems is to support the generation and evaluation of a set of alternative plans using interactions with one or more decision-makers who can systematically examine a substantive model of the decision situation and who might change their preferences and priorities during the decision-making process. DIDAS systems are designed to tackle a variety of multi-objective decision-making problems, including locational planning ones. In general, the problem is solved by a feed-back exchange of information between an analyst and a decision-maker. Many methods are available for interactive solution of the multi-objective decision-making problem. A useful review of these methods is provided by Seo and Sakawa (1988).

The DIDAS systems are based on a mathematical programming structure and the reference point approach developed by Wierzbicki (1982), which combines the well-known goal programming methodology and the method of the displaced ideal after the work of Zeleny (1976). The basic idea behind the reference point method can be described as follows: 1) the decision-maker is expected to specify reference values for each objective function under consideration; 2) modifications to the values can be made interactively as a result of learning and a better understanding of the problem during the solution process; and 3) this interactive process is continued until an ultimate compromise or satisfactory solution is determined as acceptable. Conceptually we can envisage DINAS as related to SDSS and DIDAS, and these in turn are special cases of DSS. Figure 1 shows these links.

Figure 1: Linkages among computer-based decision support systems.



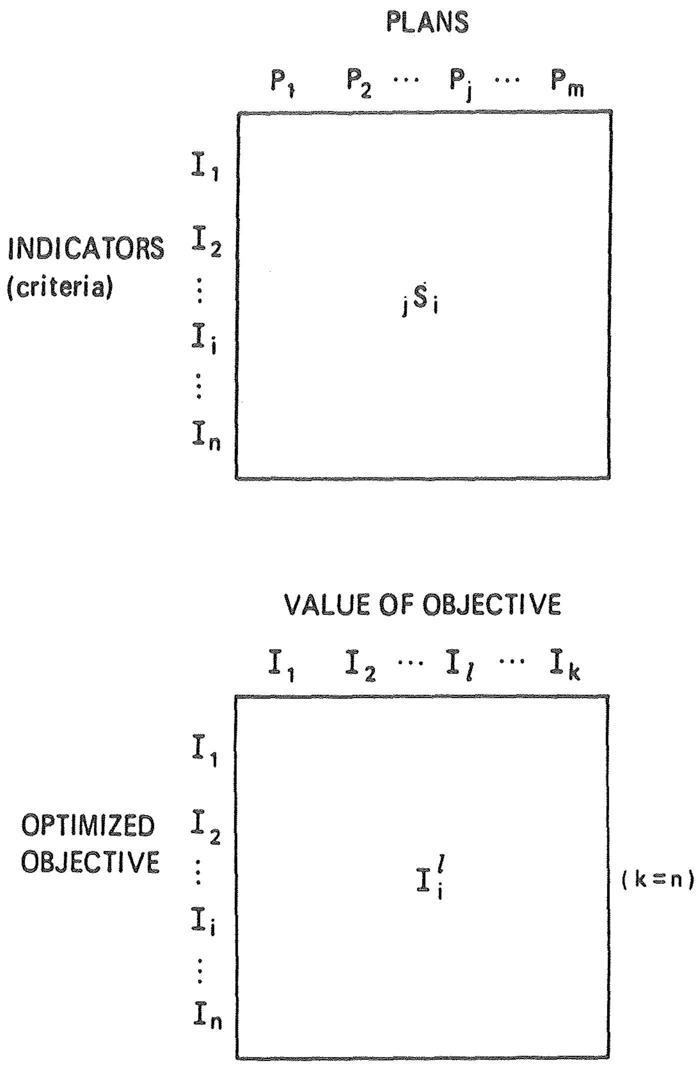
One of the most suitable DSS for the solution of a location problem is DINAS. This is similar to DIDAS systems, and it is based on the reference point technique. Full mathematical details of the algorithms used in DINAS are provided in the Reference Manual (Ogryczak et al. 1988) They will not be repeated here. The multi-objective solution of a decision-making problem is obtained in two stages:

1) in the first stage the decision-maker is provided with some initial information which gives an overview of the problem; for the location problem to be addressed in this paper these data can take the form of an impact matrix in which the columns represent the alternative locations and the rows the criteria (or indicators) used to evaluate the options (Figure 2).

The data in Figure 2 are converted to a pay-off matrix or a decision matrix which is generated by minimization or maximization of each of the objective functions (criteria) separately. This matrix provides the basis for the identification of the reference points or vectors. On the basis of the pay-off matrix, the user (analyst) can define the ideal or utopia vector (f^i) and the nadir vector (f^n).The vector f^i is usually not attainable in reality, but it is presented to the decision-maker as a lower limit to the numerical values of the objectives, which are minimized, or as an upper limit if the objective functions are maximized. Thus, after the first stage of the analysis, the decision-maker is provided with information on the solution space for each objective function.

2) in the second stage of the multi-objective analysis an interactive selection of a compromise or satisficing solution is made. The decision-maker controls the selection by two vectors: an aspiration level (f^a) and a reservation level (f^r); in the case of minimization $f^i \leq f^a \leq f^r \leq f^n$ and if an objective function is maximized $f^i \geq f^a \geq f^r \geq f^n$.

Figure 2: Plan impact matrix (A) and payoff matrix (B).



${}_jS_i$ score for plan i for criterion j

I_i^l value of the l-th objective when objective i is optimized

The following three terms are interchangeable:
indicator, criteria, objective
Tables 1 and 2 show impact matrices
Tables 3 and 4 show pay-off matrices

DINAS searches for the satisficing solution, while using a linear normalized function as the criterion in a single objective optimization; or to be more precise, the system minimizes the maximum deviation of the results from the decision-maker's expectations with respect to the objectives under consideration. The values of this function depends upon the aspiration (f^a) and reservation (f^r) levels previously specified by the decision-maker. The obtained value is an efficient, that is a Pareto-optimal solution to the original multi-objective model, i.e., the substantive model of the decision situation. This solution is presented to the decision maker as a current solution. Then, the decision-maker can judge the solution as acceptable or unacceptable. If it is found to be unsatisfactory then he or she can enter new aspiration and/or reservation levels for all or some of the objectives. Depending on this new information supplied by the decision-maker, a new efficient solution is computed and presented as a current solution. This process is repeated until the final compromise solution is deemed acceptable to the decision-maker.

THE SITE SELECTION PROBLEM USING DINAS

Originally DINAS was designed to solve a class of trans-shipment problem among demand and supply locations (see Ogryczak et al. 1988). This problem was formulated as a network model in which the network is composed of nodes that are connected by direct flow arcs. There are two types of node; the set of fixed nodes and the set of potential nodes. The fixed nodes represent fixed points of the transportation network. Each fixed node is characterized by influx and outflow of goods, people or information. The potential nodes represent new points in the network, e.g., sites for the location of a set of depots. Some subsets of the potential nodes can be considered as different versions of the same type of facilities to be located, e.g., different sizes of depots. Therefore, potential nodes are arranged in the so-called selections. Each selection is defined by the list of potential nodes and by a lower and upper number of nodes which have to be selected. Each potential node is characterized by a capacity (size of facility) which limits the maximal flow through the node.

The objective functions are introduced into the model by a set of coefficients, which are associated with arcs and potential nodes. The coefficients associated with the arcs are interpreted as the unit cost of the flow along the arc, while the potential node coefficients are considered as the cost associated with the location of the new facilities.

Taking into account the general structure of the network model, the decision-making problem can be defined as follows: determine the number, the location and the sizes of facilities (nodes) to be selected from a set of given potential nodes, and find the flows from the fixed nodes to the facilities so as to optimize a set of constraints. This problem is usually expressed in a mathematical form as a substantive model of the decision-making situation and it is then used in an interactive procedure of the style described earlier in the second section.

Depending on the decision-making context the general structure of the model can be modified and the problem can be solved using DINAS. Examples of the applications of DINAS to tackle practical problems include the search for sites for sugar-beet depots (Ogryczak et al., 1987). In this case, the decision-making situation was modelled in terms of a multi-objective trans-shipment problem with facility locations. DINAS has also been used to solve a hospital location problem in Warsaw, Poland (Malczewski, 1990; Malczewski and Ogryczak, 1990). In this application of DINAS, the general structure of the network model has been modified to obtain a location-allocation style model.

Significant modifications to the general structure of the network model are presented in this paper in order to tackle the site selection problem. Specifically, we restructure the model to tackle the problem that is referred to in the first section. First, it is necessary to redefine the network structure; this is shown in Figure 3.

The nodes *1,2,3,.., m* refer to the set of feasible optional locations, and the task is to classify these from most to least attractive, using impacts on a set of evaluation criteria or indicators for each node. Second, two hypothetical imaginary nodes are created: an origin *x* and a destination *y*, then, flows along the arcs are created. Each arc represents a unique path from *x* to *y*, via one of the option locations *1,2,3,..,m*. The structure of the network for the location choice problem is shown in Figure 2.

According to the original structure of the DINAS model, the network is described by a set of coefficients associated with potential nodes and arcs; thus:

c_j^p is a *p*-th coefficient (indicator) associated with *j*-th potential node, which should be minimized,

c_j^q is a *q*-th coefficient (indicator) associated with *j*-th potential node, which should be maximized,

c_{xj} is a coefficient associated with arc between node *x* and *j*,

c_{jj} is a coefficient associated with arc between node *j* and *y*.

Then, we can assume that:

1) $O_x = |-I_y|$,

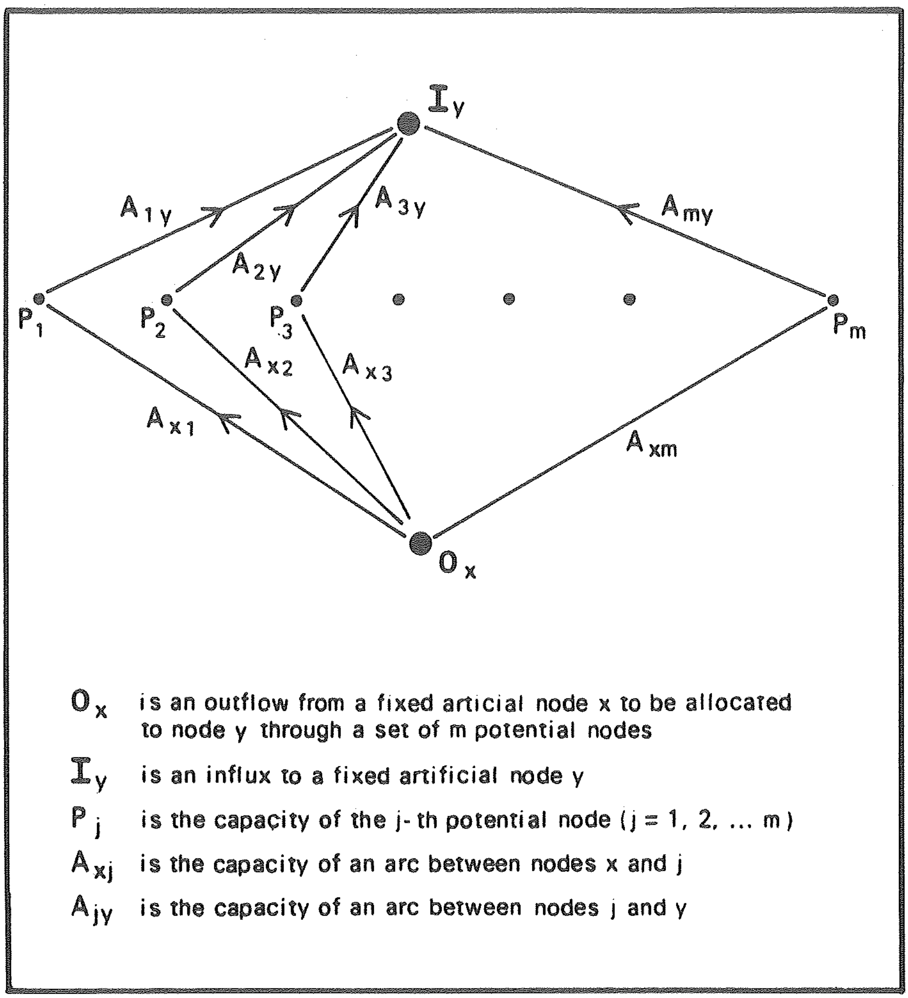
this means that the goods allocated from *x* through the *j*-th potential node is balanced at the artificial node *y*.

2) $O_x = P_j = A_{xj} = A_{jy}$,

3) $c_{xj} = c_{jy} = 1 \longrightarrow c_{xj}A_{xj} = c_{jy}A_{jy} = O_x = P_j$,

thus, the optimal allocation of goods from node *x* to node *y* through the *j*-th node is not influenced by an arc's capacity and associated coefficient, it depends exclusively on the values of the coefficients (indicators), which characterize the potential nodes; these are the alternative sites.

Figure 3: Structure of a hypothetical network for location choice problem using DINAS.



Consequently, the optimization model of the decision-making problem can be formulated as follows:

$$\text{minimize } f' = \sum_{i=1}^{m} c_j^p \alpha_j \qquad p = 1,2,3,..,k \quad (1)$$

$$\text{maximize } f'' = \sum_{i=1}^{m} c_j^q \alpha_j \qquad q = 1,2,3,..,l \quad (2)$$

subject to:

$$h^{min} \leq \sum_{j=1}^{m} \alpha_j \leq h^{max} \tag{3}$$

$$\alpha_j = \begin{cases} 1 & \text{if a good from node } x \text{ is allocated to node } j \text{ (or in other words, if the alternative location } j \text{ is chosen)} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

where h^{min} and h^{max} are respectively the minimum and maximum number of potential nodel (options) to be selected.

This model can be solved by DINAS and used by the decision-maker to find the order of attractiveness of a set of alternative locations which are evaluated on the basis of a set of indicators. Four distinct steps are involved in the procedure:

1) optimize each of the objective functions separately; this provides the decision-maker with a pay-off matrix;
2) specify the aspiration and reservation level for the values of the objective functions;
3) solve the model defined by equations (1), (2), (3) and, (4) for a given aspiration and reservation level and for $h^{min} = 0$ and $h^{max} = 1$; as a result, a set of efficient or pareto-optimal solutions is obtained;
4) exclude the best solution and for the remaining subset of alternative sites repeat steps 3 and 4 until all alternative sites are ordered from the best to the worst.

This procedure can be performed for different aspiration and reservation levels and for various sets of the evaluation indicators. In the next section an application of this revised structure of DINAS is applied to a small set of data for two districts in Zambia.

DINAS APPLICATION TO A SITE SELECTION PROBLEM

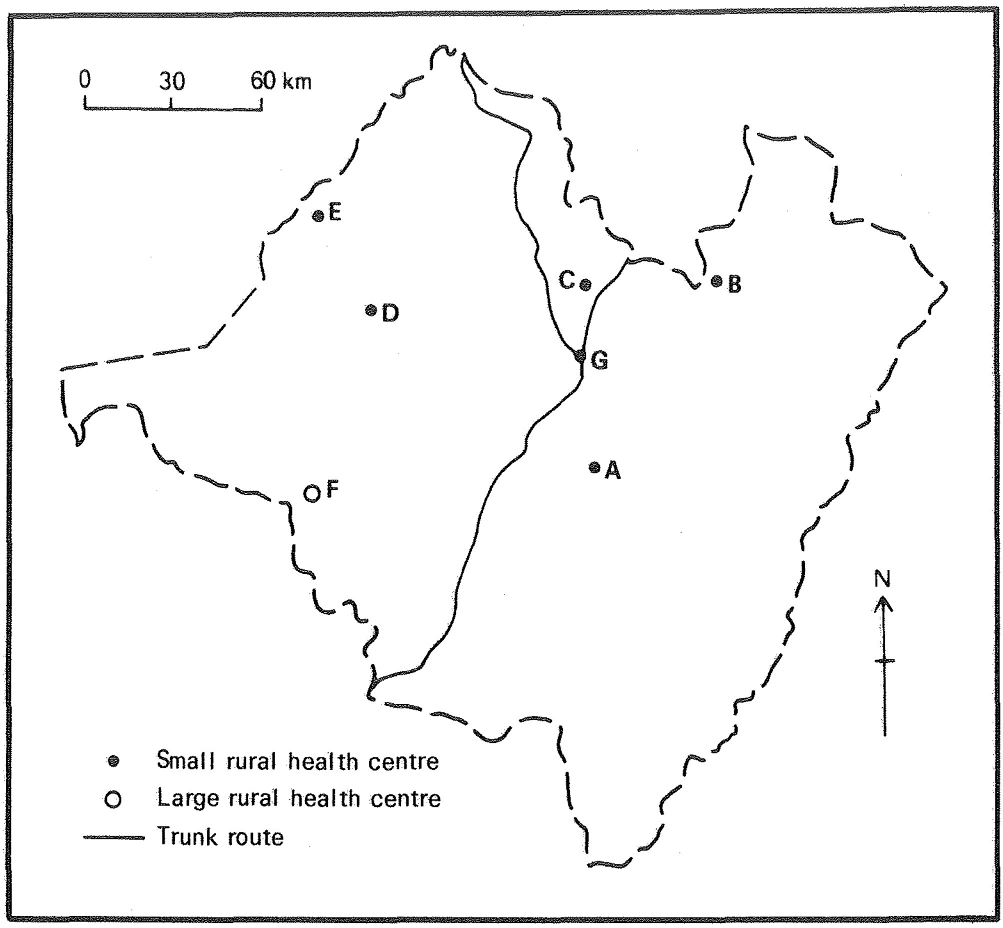
Data

To illustrate the use of DINAS for tackling a site selection problem we have used a set of data for the districts of Mpika and Sesheke in Zambia (Figures 4 and 5). The problem is to select locations for new health centers from a given set of small health centers. The data have been taken from Massam et al., (1986).

For each district, the demand for facilities is described by a population distribution map which is defined as a set of points; each point represents the location of a village or a population cluster of at least 500 persons.

The population of Mpika is 44,500, and this is allocated to a set of 79 points. Eighty-four points are used to describe the distribution of the current population of 47,500 in Sesheke.

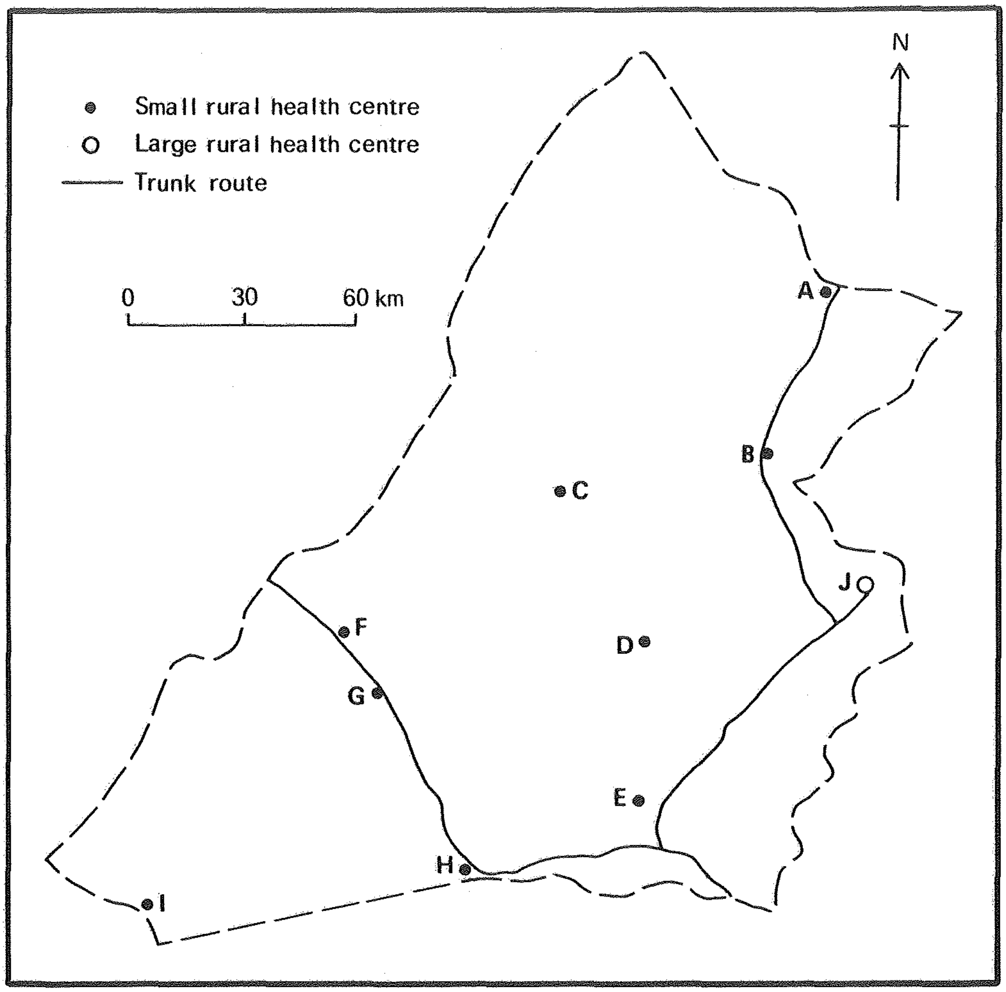
Figure 4: Distribution of rural health centers in Mpika district, Northern Province, Zambia, 1985.



Six indicators have been used to help in choosing which rural health center should be upgraded:

1) the average distance travelled to the nearest center ($\bar{d}$) km;
2) the standard deviation of the average distances (d_s) km;
3) the maximum distance that has to be travelled to reach a center (d_m) km;
4) the population within 12 km of a center (p_{12});
5) the population within 30 km of a center (p_{30});
6) the distance to the next nearest center (d_n) km.

Figure 5: Distribution of rural health centers in Sesheke district, Western Province, Zambia, 1985.



Overall the evaluation is made on the basis of physical accessibility as measured by direct distance and the size of catchment areas. We suggest that the first three indicators focus on the essential characteristics relating to effectiveness and equity questions which are associated with the location of centers. In particular, ($\bar{d}$) can be considered as a measure of the general accessibility of the center to all the potential patients, whereas d_m is specifically an indication of the distance that will have to be travelled by a minority of the population. Further, d_s offers a view concerning the variations in distances that potential patients will have to travel. In the interests of maximizing effectiveness and equity we argue that the ideal location for a center is the one which has the minimum values for $(\bar{d})$, d_m, d_s.

The fourth and fifth indicators measure the size of the catchment area which is relevant if we consider that there exists a threshold distance beyond which an individual is unwilling or unable to travel. Two arbitrary values of 12 km and 30 km have been selected. Clearly the larger the population contained within the catchment area, the greater the utilization of the center, and hence the better the location choice. Therefore, the purpose of these two indicators is to identify the center which has the maximum population.

The final indicator attempts to measure the distribution of centers throughout the district by considering their proximity to one another. We argue that in the interests of equality it is important to ensure that all the centers are dispersed. In an attempt to capture this element of the distribution pattern we suggest that d_n should be maximized for the ideal location.

Tables 1 and 2 show the values of the indicators for each of the alternative sites for both districts. These two sets of indicators have been used as input data for the site selection problem. Data for the in situ characteristics of each site are not readily available. A complete study should include local conditions related to land costs, availability of water and electricity, as well as the availability of personnel in the vicinity to staff the center. A wide variety of indicators can be incorporated into the analysis.

Table 1: Basic data: Mpika District.

	Indicators					
	1	2	3	4	5	6
Alternative sites	$(\bar{d})$	(d_s)	(d_m)	(p_{12})	(p_{30})	(d_n)
A	85	25	152	500	4500	43
B	111	12	184	500	2500	44
C	79	22	144	1500	5500	22
D	80	35	184	1500	6000	37
E	100	47	221	0	3500	37
F	122	9	168	2000	10500	67
G	67	18	122	500	500	22

Table 2: Basic data: Sesheke District.

	Indicators					
	1	2	3	4	5	6
Alternative sites	($\bar{d}$)	(d_s)	(d_m)	(p_{12})	(p_{30})	(d_n)
A	133	13	272	0	1500	52
B	81	53	224	2000	5000	45
C	81	29	176	500	3000	45
D	59	26	168	500	4000	43
E	61	34	160	3000	8500	48
F	98	31	168	0	3500	33
G	91	32	176	500	3000	22
H	84	41	192	6000	6500	48
I	152	9	264	1000	1500	90
J	79	47	231	1500	6000	45

Pay-off matrices

In the first step of the procedure for the site selection problem using DINAS, each objective (criterion) is optimized separately. As a result, a pay-off matrix is obtained. Table 3 shows the results for the Mpika District. It can be seen that the most impressive feature of this problem is a conflict between the site selection of F and G. Whichever objective is optimized, the most preferred location is F and the worst alternative is G or vice versa. Therefore the pay-off matrix is composed of only two different solutions.

Table 3: Pay-off matrix for Mpika District.

	Objective value					
	1	2	3	4	5	6
Optimized objective	($\bar{d}$)	(d_s)	(d_m)	(p_{12})	(p_{30})	(d_n)
1 ($\bar{d}$)	67	18	112	500	500	22
2 (d_s)	122	9	168	2000	10500	67
3 (d_m)	67	18	122	500	500	22
4 (p_{12})	122	9	168	2000	10500	67
5 (p_{30})	122	9	168	2000	10500	67
6 (d_n)	122	9	168	2000	10500	67

The structure of the pay-off matrix, and consequently the locational conflict, is more complex for the Sesheke District (see Table 4). There are four alternative sites (D, I, E, H) which are characterized by obtaining the highest value on at least one of the indicators. On the other hand, all of these sites, except E, are the least satisfactory alternatives for at least one of the criteria. This might suggest that the option E should be preferred over other alternatives.

Table 4: Pay-off matrix for Sesheke District.

	Objective value					
Optimized objective	1 ($\bar{d}$)	2 (d_s)	3 (d_m)	4 (p_{12})	5 (p_{30})	6 (d_n)
1 ($\bar{d}$)	59	26	168	500	4000	43
2 (d_s)	152	9	264	1000	1500	90
3 (d_m)	61	34	160	3000	8500	48
4 (p_{12})	84	41	192	6000	6500	48
5 (p_{30})	61	34	160	3000	8500	48
6 (d_n)	152	9	264	1000	1500	90

Having computed the pay-off matrices, DINAS provides the decision-maker with two reference vectors: the utopia and nadir vector. From Tables 3 and 4 we can read the utopia vector for Mpika as:

$\bar{d} = 67;\ d_s = 9;\ d_n = 112;\ p_{12} = 2000;\ p_{30} = 10500;\ d_n = 67;$

and for Sesheke:

$\bar{d} = 59;\ d_s = 9;\ d_n = 160;\ p_{12} = 6000;\ p_{30} = 8500;\ d_n = 90;$

and the nadir vector for Mpika:

$\bar{d} = 122;\ d_s = 18;\ d_n = 168;\ p_{12} = 500;\ p_{30} = 500;\ d_n = 22;$

and for Sesheke:

$\bar{d} = 152;\ d_s = 41;\ d_n = 264;\ p_{12} = 500;\ p_{30} = 1500;\ d_n = 43.$

These vectors provide the decision-maker with information on the minimum and maximum attainable levels of each objective; i.e., the boundaries between which the solution to the problems have to be found.

Table 5: Results of experiments: Mipka District.

Experiment	Indicators included	Aspiration level	Reservation level	Efficient solutions Steps** 1	2	3	4	5	6	7
1	1,2,3,4,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^n$ *	F G	C B D G	D B G	A B G	B E G	G E	E
2	1,2,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$	F G	C B D G	G B D	A B D	D B	B E	E
3	1,2,3,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^n$	F G	A B D G	C B D G	G B D	D B	B E	E
4	1,2,3,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$	F G	C B D G	A B D G	G B D	D B	E B	B
5	1,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$	F G	C D G	G D	D A	A	E B	B
6	1,2,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$	F G	C B D G	D B G	A B G	G B E	E B	B
7	1,2,3,4,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$ $q_i^r = q_i^n$	G F	C F	A D F	D F	E F	B F	F
8	1,2,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$ $q_i^r = q_i^n$	G F	C F	A D F	D F	E F	B F	F
9	1,2,3,4,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$ $q_i^r = q_i^n$	F G	C B D G	D B G	A B G	B E G	G E	E
10	1,2,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$ $q_i^r = q_i^n$	F G	C B D G	D B G	G A B	A B	B E	E

Note: * q_i^u, q_i^a, q_i^r, q_i^n are utopia, aspiration, reservation and nadir values for the *i*-th indicator (i=1,2, ... 6).

** the best solution (marked in bold type) is excluded at each step.

EXPERIMENTS

Once the decision-maker is provided with the initial information on the problem solution, he or she can work interactively with the computer (DINAS) system. In this study ten hypothetical experiments (interactions) for each district have been designed (see Table 5 (p. 17) and Table 6).

Table 6: Results of experiments: Shesheke District.

Experiment	Indicators included	Aspiration level	Reservation level
1	1,2,3,4,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^n$
2	1,2,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$
3	1,2,3,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^n$
4	1,2,3,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$
5	1,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$
6	1,2,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^n$
7	1,2,3,4,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$
			$q_i^r = q_i^n$
8	1,2,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$
			$q_i^r = q_i^n$
9	1,2,3,4,5,6	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$
			$q_i^r = q_i^n$
10	1,2,3,4,5	$q_i^a = q_i^u$	$q_i^r = q_i^a + 0.5\ (q_i^n - q_i^u)$
			$q_i^r = q_i^n$

Note: * q_i^u, q_i^a, q_i^r, q_i^n are utopia, aspiration, reservation and nadir values for the i-th indicator (i=1,2, ... 6).

** the best solution (marked in bold type) is excluded at each step.

In experiment 1 all indicators are taken into consideration; while in experiments 2-6 one or two indicators are excluded from the analysis. At the same time, in experiments 1-6 all indicators are considered to be equally important. Consequently, the aspiration and reservation levels are equal to the utopia and nadir vectors respectively. In experiments 7-10 all indicators have been analyzed, but in experiments 7 and 8 the reservation level for indicator 1 has been shifted to the mid-point of the nadir-utopia distance; this means that a preference is given to indicator 1. Similarly, in experiments 9 and 10, indicator 4 is considered to be the most important; the rest of the indicators in experiments 7-10 are equally important.

Efficient solutions Steps**									
1	2	3	4	5	6	7	8	9	10
E D H I	H D I	J B D I	D B I	C B F I	B F I	G F I	I F	F A	A
E D H I	H D I	J B D I	D B I	C B F I	G B F I	B F I	F I	I A	A
D E I	E C I	C H I	H F I J	F J	J G I	B G I	G I	I A	A
D E I	E I	F H I J	C H I J	G H I J	H I J	J B I	B I	I A	A
E D H	D H	H F J	B F J	J F	C F I	G F I	F I	I A	A
E D H I	H D I	J B D I	B D I	D I	C F I	G F I	I F	F A	A
E D H I	H D I	J B D I	D B I	C B F I	B F I	G F I	F I	A I	I
E D H I	H D I	J B D I	D B I	C B F I	G B F I	B F I	F I	A I	I
H D E I	E D I	J B D I	B D I	I D	D A	C A F	G A F	F A	A
H D E I	E D I	J B D I	B D I	I D	D A	C A F	G A F	F A	A

RESULTS

The results of these 10 experiments are displayed in Tables 5 and 6. For each experiment and for each step of the procedure all efficient solutions are given and also the order of the options from the best to the worst is shown.

In the case of Mpika District, the results confirm the suggestion made on the basis of the pay-off matrix that F and G are the most appropriate sites for a new health center. Option F is the best alternative for all experiments except 7 and 8. In these two experiments, a preference is given to indicator 1 and consequently the option G is preferred to F. Thus, it can be argued that site F is the best choice. One should note that F is the largest settlement center in the Mpika District. It seems that G and C can be considered to be the second choice. In contrast to option F, sites G and C are situated close to the major roads. Options B and E appear to be the least favorable alternatives and these sites are located on the periphery of the district.

The results for Sesheke District (Table 6) suggest that options E and H are preferred over other alternative sites. If the preference is given to the indicator 4 (the population within 12 km), then H is better than E. Moreover, if the indicator 5 is excluded from the analysis (experiment 3 and 4), then D is preferred over the other options. On the other hand, option D performs badly in other experiments. Therefore, the alternative sites E and H can be recognized as the best ones. These two sites are close to the major road system, and at the same time they contain the largest concentrations of population in the district. Further, the results clearly shows that options D and J are the second choice and the sites A and I, situated at the outskirts of the region, are the worst options.

CONCLUSIONS

In Table 7, a comparison is made of the results provided by DINAS and those offered by a concordance analysis model as reported in Massam et al. (1986). A set of eight experiments was used to derive results using concordance analysis. Full details are provided in Massam et al. (1986). Because the two sets of experiments—DINAS (10) and CONCORDANCE (8)—do not match identically, given the different characteristics of the models, it is not reasonable to make a direct comparison of the individual results. In Table 7 we present aggregate results in the form of clusters of sites ranging from the most attractive (BEST) to least attractive (WORST). For both districts there is perfect agreement for the best and and worst options, and also a high degree of correspondence in the overall ordering of the sites. The general conclusion is that either DINAS or a concordance method could be used to help in the search for appropriate locations for new health care facilities in Zambia. The final choice of the method depends upon the availability of appropriately skilled analysts. However, given that it is important to consider the implementation aspects of the problem, it might be preferable to use a DSS, such as DINAS, which would allow decision-makers to be involved in the analysis from the outset. Such involvement might serve to enhance the credibility attached to the final results. We suggest that there is a need to explore this aspect of the process to complement the study on consensus which was undertaken using this data set and reported in Massam (1988a).

Table 7: Comparison of results: DINAS and CONCORDANCE model.

MPIKA DISTRICT		
	DINAS	CONCORDANCE
BEST	F	F
	C D G	A C D
WORST	A B E	B E G
SESHEKE DISTRICT		
BEST	E H	E H
	D J	B J
	B C G	G I
	F I	C D
WORST	A	A F

We also suggest that a DSS can help organize the collection of data in a suitable format for undertaking discussions on ideal options, as well as acceptable levels of achievement for the impacts on the indicators. Among the key issues which render most public facility location problems complex we must recognize risks and uncertainties. There are no easy or technical solutions to the problems of selecting the criteria which are to be used. It is very hard to determine the magnitude and significance of the impact scores so as to determine the set of feasible options, nor is it easy to formulate objectives and order or weight the relative importance of the indicators. The aggregation of impacts involves making trade-offs which are usually very difficult to justify technically. Such trade-offs may well be different for the users, the producers and the managers of health care facilities.

Probably the best planning environment we can hope for is one in which the chances of making planning mistakes is kept to a minimum and the final decision has well-recognized legitimacy. For the location choice problem and the generic planning problem there are two classic mistakes; first the acceptance of a site (or plan) when it should be rejected and second, the rejection of a site (or plan) when it should be accepted. If DSS can help to reduce the chances of making these two fundamental categories of planning errors, as well as contributing to a milieu within which decisions are made expeditiously, and regret is kept to a minimum, while aiding responsible choices and accountable decisions, then real progress will have been made. It is our hope that DSS will contribute to this long-term social objective of improving the quality of planning by informed collection and analysis of data. Further, we suggest that DSS can be incorporated into theoretical improvements on the planning of public and private goods and services by providing an environment which stresses openness and accountability.

NOTES

This paper is a development of a lecture given by Prof. B.H. Massam at the Ben-Gurion University of the Negev under the title: "Choice in space: the analysis of utilization patterns of health care facilities," March 12, 1989. This research was supported by a grant from the Faculty of Arts, York University and the Social Sciences and Humanities Research Council, Canada.

REFERENCES

Armstrong, M.P, Densham, P.J. and Rushton, G. (1986). Architecture for a micro-computer based spatial decision support system, In D.F. Marble (ed.), Proceedings, Second International Symposium on Spatial Data Handling. Williamsville, NY: International Geographical Union, pp. 120-31.

Bennet, V.L., Eaton, D. and Church, R. (1982). Selecting sites for rural health workers. *Social Sciences and Medicine,* 16:63-72.

Colerni, A. (1987). Optimization techniques in locational modelling. In: C.S. Bertuglia, G. Leonardi, S. Occelli, G.A. Rabino, R. Tadei, and A.G. Wilson eds.), *Urban Systems: Contemporary Approaches to Modelling.* London: Croom Helm, pp. 253-333.

Day, P. and Klein, R. (1987). *Accountabilities: Five Public Services.* London and New York: Tavistock Publications.

Densham, P. and Rushton, G. (1987). Decision support systems for locational planning. In: R.G. Golledge and H. Timmermans, *Behavioral Modelling in Geography and Planning.* New York: Croom Helm, pp. 56-90.

Fisher, H.B. and Rushton, G. (1979). Spatial efficiency of service locations and the regional development process. *Papers of the Regional Science Assoc.* 52:83-97.

Horn, M., O'Callaghan, J. and Garner, B. (1988). Design of integrated systems for spatial planning tasks. In: *Proceedings Third International Symposium on Spatial Data Handling,* August 17-19. Sydney, pp. 107-116.

Jones, K. and Simmons, J. (1987). *Location, Location, Location: Analyzing the Retail Environment.* Toronto: Methuen.

Keen, P.G.W. and Scott-Morton, M.S. (1978). *Decision Support Systems: An Organizational Perspective.* Reading, MA: Addison-Wesley.

Lewandowski, A. and Wierzbicki, A.P. (1987). Theory, software and test examples for decision support systems. Working Paper, International Institute for Applied System Analysis. Luxenburg, Austria.

Lonsdale, R.E. and Enyedi, G. (eds.) (1984). *Rural Public Services: International Comparisons*. Boulder, CO: Westview.

Malczewski, J. (1990). Central facility location and environmental health. *Environment and Planning A*, 22 (in press).

Malczewski, J. and Ogryczak, W. (1990). An interactive approach to the central facility location problem. *Geographical Analysis*, (in press).

Massam, B.H. (1975). *Location and Space in Social Administration*. London: Edward Arnold, Ltd.

Massam, B.H. (1980). *Spatial Search: Applications to Planning Problems in the Public Sector*. Oxford: Pergamon.

Massam, B.H. (1988a) Evaluation and Implementation: The Location of Health Centres in Zambia, A Study in Consensus. Institute of Population Studies, University of Exeter, U.K.

Massam, B.H. (1988b) Multi-criteria decision making (MCDM) techniques in planning. *Progress in Planning*, 30:1-84.

Massam, B.H. (1988c). The location of public facilities: In search of a generic problem. In: B.H. Massam (ed.), *Complex Location Problems: Interdisciplinary approaches, Institute for Social Research*. Ontario, Canada.: York University.

Massam, B.H., Akhtar, R. and Askew, I.D. (1986). Applying operations research to health planning: Locating health centres in Zambia. *Health Policy and Planning*, 4:326-334.

Massam, B.H. and Askew, I. (1984). A theoretical perspective on rural service provision: A systems approach. In: R.E. Lonsdale and G. Enyedi (eds.), *Rural Public Services: International Comparisons*. Boulder, CO: Westview Press, pp. 15-38.

Massam, B.H. and Malczewski, J. (1990). Complex location problems: Can decision support systems help? *The Operational Geographer*, (in press).

Ogryczak, W., Studzinski, K. and Zorychta, K. (1987). General concepts of the Dynamic Interactive Network Analysis System (DINAS). *Archiwum Automatyki i Telemechaniki*, 32:277-287.

Ogryczak, W., Studzinski, K. and Zorychta, K. (1988). *Dynamic Interactive Network Analysis System—DINAS, Version 2.1: User's Manual*, WP-88-114, IIASA, Luxembourg.

Robinson, V.B. (1983). *Urban Data Management Software (UDMS) Package: User's Manual*. United Nations Centre for Human Settlements (HABITAT), Nairobi.

Robinson, V.B. and Coiner, J.C. (1986). Characteristics and diffusion of a microcomputer geoprocessing system: The urban data management software (UDMS) package. *Computers, Environment and Urban Systems*, 10:165-173.

Seo, F. and Sakawa, M. (1988). *Multiple Criteria Decision Analysis in Regional Planning: Concepts, Methods and Applications*. Dordrecht, Holland: D.Reidel Publishing Company.

Taylor, J. and Taylor, W. (1987). Searching for solutions. *PC Magazine*, 6:311-337.

Wierzbicki, A.P. (1982). A mathematical basis for satisficing decision making. *Mathematical Modelling*, 3:391-405.

Wanmali, S. (1983). Service Provision and Rural Development in India: A Study of Miryalguda Talua. Research Report 37. International Food Policy Research Institute, Washington, DC.

Zeleny, M. (1976). The theory of displaced ideal. In: M. Zeleny (ed.), *Multiple Criteria Decision Making*. Berlin: Springer Verlag, pp. 153-206.