

Applying operations research to health planning: locating health centres in Zambia

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Accessibility to health care facilities, particularly in rural areas with dispersed populations, is a major concern of primary health care policies. The physical accessibility of rural health care facilities is often assessed in terms of their location relative to those who will use them. However, the final choice of location for a facility will often depend on a trade-off between many criteria including not only its physical accessibility for the users, but also its costs to the provider, its political value to local leaders, etc. In this paper a technique will be presented which can help health policy-makers and planners in deciding on the optimum location for rural health facilities by taking into account the different criteria of these various interest groups. The technique is intended to help in a prospective evaluation of alternative feasible locations; it is therefore appropriate for operations research. Two examples are taken from Zambia to illustrate how the approach could be used in choosing the most suitable location for upgrading a rural health centre in a district.

Introduction

One of the main objectives of primary health care policies, particularly for countries with a large, dispersed rural population, is to increase the physical accessibility of the health care facilities provided by the state. This objective derives from the need to improve the availability of basic health services to rural dwellers, and to reduce the inequalities created by a centralized health system which tries to serve a widespread population. Planners often seek to meet this objective by decentralizing the existing health care system so as to provide essential services at the community level with referral to more specialized services through a hierarchy of health centres and hospitals.

However, even if a government does reallocate resources towards decentralizing and reorganizing a health care system to improve service availability at the community level, it will be impossible to provide every community with a primary health care centre; often it will be a matter of providing one centre to serve a number of communities. Moreover, in most countries some health care facilities already exist in rural areas and these need to be integrated into a hierarchical system.

Thus when considering the accessibility of primary health care facilities, policy-makers and planners need to take into account not only the optimum location in terms of accessibility to a number of communities, but also the constraints imposed on the choice of location by existing facilities. Although relocation may increase accessibility to the users, it may also increase the costs to the provider, that is, the continued use of an existing facility may be perceived by planners as a saving and its relocation an unnecessary cost.

In this paper we consider the problem of selecting possible locations for rural health centres in Zambia, given that a set of primary health centres currently exists. We present a planning method designed to tackle this type of problem which has practical applications in the organization of information, and thus can help those who are responsible for the implementation of a decentralization policy. A fuller description of the method is given in Askew and Massam (1986). The utility of the model is demonstrated for a hypothetical problem using a small set of data for the districts of Mpika and Sesheke in Zambia.

A framework for locational planning

At the outset we can identify three types of planning framework which might be used for tackling the problem of selecting new locations for rural health centres. These frameworks are based on the assumptions that the economic costs to the planners have already been determined through budgetary allocations and that the physical accessibility of the facilities to the potential users is the central concern.

First, there is the framework which focuses on a single criterion to evaluate alternative locations: that accessibility to the population must be maximized. This criterion is commonly defined as the average distance travelled by the service users to the nearest facility. A formal linear programming algorithm which minimizes this distance is used and the location which has the lowest value for average distance is declared to be the optimum location. Examples of this type of framework are given in Reid et al (1986).

Within this planning framework there is one decision criterion – the average distance travelled by potential service users – and there is one group of people responsible for making the choice of location – the health planners. This framework is commonly utilized, but rather than the choice being made by planners on an explicit criterion of accessibility, locations are more often evaluated by political leaders or administrators on the criterion of expediency. For example, disgruntled citizens in a particular region who threaten to disrupt the stability of a government may need to be placated and thus may receive a health centre. However, such an approach is reactive and leaves those who have no advocates or who lack political skills at a disadvantage.

A second type of planning framework is one in which the single group influencing the decision is replaced by the inclusion of all those who will be affected by the decision. Thus not only would the planners, administrators and political leaders be involved because they will bear the financial and political costs of the chosen location, but also the potential users of the services would be involved. This framework explicitly requires community participation in the planning process and is the framework frequently alluded to in policy statements on primary health care.

However, studies are beginning to show (e.g. Ugalde 1985, de Kadt 1983) that, whilst the participation of communities in the implementation of programmes is gradually developing, their involvement in the planning process is, in most countries, either nominal, manipulated or non-existent. Unless the political and administrative aims and procedures of health care planning are reoriented towards participatory decision-making this framework will remain an illusion of the policy-makers' rhetoric.

Furthermore, the second type of framework will necessarily be concerned with multiple criteria because the multiple interest groups involved in the planning process will undoubtedly place different weight on different criteria. Put simplistically, the planners and administrators will probably be most concerned with the cost, the users with the accessibility and the politicians with the expediency of the location of a primary health centre. To include each of these criteria in the decision-making will require trade-offs between them which will inevitably result in the group with most power pushing through decisions by virtue of being able to promote their particular criterion most strongly. The service users are likely to be the least powerful in such a process and thus their views are least likely to be heard.

A third planning framework is one in which multiple criteria and multiple interest groups are recognized, but these are incorporated into a formal planning procedure rather than debated through a highly political planning process. Such an approach seeks to integrate the 'objectivity' of a formal planning procedure (cf. the first framework) with the need to include the interests of all those who will be affected by the outcome. While it is recognized that the search for an ideal formal method which allows hard data and rigorous definitions of the interest groups and criteria to be used is a chimera, we subscribe to the view that an approximation to an ideal may go some way to help improve the quality of the debate among the interested parties. Further, such a method may help in the prospective evaluation of alternative solutions to the location problem and hence place policy-making on a firmer basis for careful scrutiny than the case when decisions are based solely on intuition and judgement. We might also suggest

that the method could be used for pedagogic purposes using hypothetical sets of data.

In this paper we describe such a method and show how it could be applied to a specific location problem for two districts in Zambia. An overview of the method is presented after a general discussion on criteria that will be used to measure physical accessibility. The method is then illustrated using data from Zambia and some aspects of applying the method in practice are discussed.

Measuring physical accessibility

It has been suggested that in making decisions regarding the location of primary health care facilities a wide range of criteria are normally taken into account and that these criteria quite often reflect the interests of particular groups. For the purpose of illustration we will concentrate on one criterion, physical accessibility, but this criterion itself can be operationally defined by a number of indicators depending on whose interests are being primarily considered. Thus the problem to be addressed is one of maximizing the accessibility of primary health centres in rural Zambia, assuming that other factors are equal.

Bennett et al (1982) suggest that accessibility to an unserved population is critical. The emphasis on accessibility is stressed in the cross-cultural work of Joseph and Phillips (1984) in their studies on health care utilization patterns and location problems, and Wanmali (1983), who places health care into the broader perspective of rural development in India, again places heavy emphasis on the need to locate service centres in accessible villages.

While many would agree that the use of accessible locations for health care facilities is an admirable objective, there are severe problems when attempts are made to provide operational definitions for the term. In the interests of the overall effectiveness of the whole primary health care system we might argue that accessibility should be measured by the average time taken by an individual to reach a centre. On the other hand, in the interests of improving the services to those who are currently furthest from a facility we could define accessibility in terms of the maximum distance travelled. With this

criterion in mind we can argue that the best location is the one that minimizes the maximum distance travelled by anyone. This contrasts with that location which is the site with the lowest average distance value. A further measure of accessibility is provided by calculating the standard deviation for the distances associated with a particular centre. These three ways of measuring accessibility will be used in the examples below. They will complement three other criteria, two of which focus on the size of the catchment area for a centre and the final one which considers the degree of dispersion of centres throughout the study region.

The planning method

The formal method we propose will allow multiple criteria or indicators to be included in the evaluation process and also provides a mechanism for making explicit the relative importance of each criterion through assigning 'weights' to each one. The use of this method allows a number of hypothetical experiments to be conducted by the planners by varying the criteria and weights. In this way it is possible to provide a set of feasible solutions to those who have the task of making the final decision. By conducting these hypothetical experiments in advance, a number of alternatives can be explored and assessed without incurring particularly high costs. This method can therefore be added to the tools of the operations research approach which is rapidly gaining popularity amongst health planners, particularly for primary health care (Blumenfeld 1985).

We suggest that the utility of the method can be enhanced if all possible interest groups are involved in the formulation of the problem and the definition of the experiments. In this paper we are proposing a methodology which requires an explicit and formal statement of each interest group's opinion of a possible location in terms of certain criteria. How the opinions of the interest groups are to be obtained and articulated is obviously a major concern to planners, but it is also a problem which can only be solved by those actually involved in the planning process in a particular situation; for this reason the problem will not be addressed here.

The basic data required for the method are presented in the form of an options table of the

style shown in Table 1. Each cell in this table is assigned a value; $m v_n$ refers to the value for option m with respect to criterion n . The options could be the feasible alternative locations for a rural health centre and the criteria could include different indicators of accessibility. The value in each cell is the score for location m according to the indicator of accessibility, n .

Table 1. An example of an options table

	Criteria			
	1	2	3	n
Options				
a				
b				
c				
\vdots				
m				$m v_n$

Once an options table has been constructed the next task for the planners is to define a series of experiments. It is at this step that the options of the different interest groups can be included in the analysis. As suggested previously, different groups might value each criterion differently and these values can be defined through assigning a set of weights to the criteria. Each different set of weights is therefore one experiment. For example we could consider that all the criteria are equally important, and that all values have been accurately measured. This could be the initial experiment.

Other experiments would be defined according to the different interest groups by giving different weights to the criteria, by adjusting the number of criteria which are being considered, or by adjusting the values to reflect possible errors.

The final step in the method is to undertake a classification of the options using the criteria weights and the values. The procedure which is used is concordance analysis and full details are given in Massam (1980) (a computer program for micro-computers is available). Basically pairs of options are compared according to the values. An example is given in Table 2; four criteria are used, each has a weight of 0.25. An ideal option is also defined.

The concordance c_{ab} is given by comparing options a and b for each criterion and a score is calculated by summing the weights of those

Table 2. Example of an options table with weights assigned

	Criteria			
	1	2	3	4
Options				
a	4	9	3	7
b	6	11	5	8
ideal	6	9	3	7
Weights	0.25	0.25	0.25	0.25

criteria for which option a is preferred to b . This score is then divided by the sum of all weights. For this example:

$$c_{ab} = \frac{0 + 0.25 + 0.25 + 0.25}{0.25 + 0.25 + 0.25 + 0.25} = 0.75$$

If $c_{ab} = 1.0$, this indicates that a is preferred to b for all criteria; if $c_{ab} = 0.0$ then a is never preferred to b . A value of $c_{ab} = 0.5$ suggests indifference between the two options. It should be noted that $c_{ab} + c_{ba} = 1.0$. The data provided in the options table can be analysed using this procedure to produce a square concordance matrix. If five options are considered, the matrix is 5 by 5. Each cell contains the concordance between all pairs of options. The values in this matrix are then summed across the rows to give a total and the option with the highest value is the most preferred. The options can be ordered from best to worst according to these totals.

For each experiment the results can be calculated and a comparison made between the experiments to identify any potential agreements or conflicts between options. This information can then be incorporated into the decision-making process. In order to illustrate the method the next section will consider two sets of empirical data drawn from rural areas in Zambia which could be used to help in choosing which rural health centre should be upgraded based on the criterion of accessibility.

Two illustrative examples

The examples set out here are for illustrative purposes and so only a modest set of indicators have been included. The emphasis is placed on physical accessibility as measured by direct distance and the size of catchment areas. For each of the two study regions, Mpika District and Sesheke District, the demand for facilities is

described by a population distribution map on which there is 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 to describe the spatial distribution. Some 84 points are used to describe the distribution of the current population of 47 500 in Sesheke.

The indicators that have been selected for this exercise are listed below;

- 1 Average distance travelled to the nearest centre (\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 centre (d_m) km.
- 4 The population within 12 km of a centre (p_{12}).
- 5 The population within 30 km of a centre (p_{30}).
- 6 The distance to the next nearest centre (d_n) km.

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 centres. In particular, \bar{d} can be considered as a measure of the general accessibility of the centre 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 could argue that the ideal location for a centre is the one which has the minimum values for \bar{d} , d_m and d_s .

The fourth and fifth indicators measure the size of the catchment area which are 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 centre and hence the better the location choice. Hence for these two indicators p_{12} and p_{30} , the purpose is to identify the centre which has the maximum population.

The final indicator attempts to measure the distribution of centres throughout the district by considering their proximity to one another. We argue that in the interests of equity it is important to ensure that all the centres 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.

Mpika District

A base map of the Mpika District is shown in Figure 1. Currently there are six small rural health centres and one large health centre. The task is to use the set of six indicators to try to identify the most appropriate centre for upgrading. The options table is given in Table 3. From this set of data we can identify the best sites using individual indicators as identified by a concordance analysis. A summary is provided in Table 4.

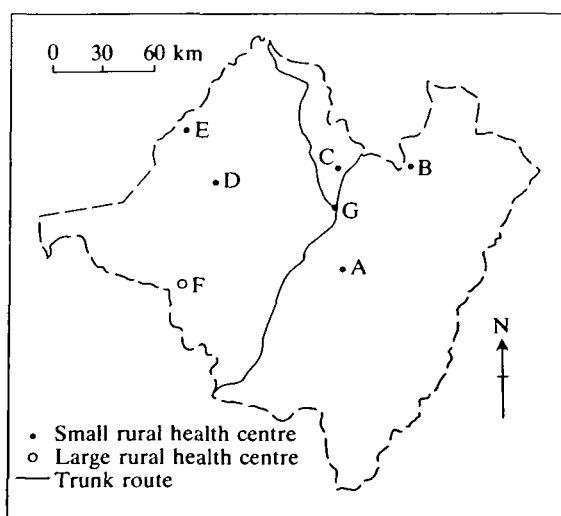


Figure 1. Distribution of rural health centres in Mpika District, Northern Province, Zambia, 1985

This suggests that it is the largest centre (F) which should be upgraded. While there appears to be considerable agreement among the selection of the best site for each indicator, there is no clear second choice. Further this strategy for making a selection does not allow the opinions of different interest groups to be considered through the application of weighting

Table 3. Basic data: Mpika District

		Indicators					
		1(\bar{d})	2(d_s)	3(d_m)	4(p_{12})	5(p_{30})	6(d_n)
Alternative sites	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	112	500	500	22
Benchmark		67	9	112	2000	10500	67
Optimum		min	min	min	max	max	max

Table 4. Best sites using single indicator, Mpika District

Criteria	Best site	2nd	3rd
1	G	C	D
2	F	B	G
3	G	C	A
4	F	C	D
5	F	D	C
6	F	B	A

schemes to the set of indicators. To illustrate the experimental operations research approach proposed previously, eight experiments were designed. Details are given in Table 5.

In experiment 1 all indicators are included in the analysis and they are all considered to be equally important. Experiments 2–4 also hold that the indicators included are equally important, but some have been excluded on the grounds that they may be thought to be unimportant by certain interest groups. Thus the measure of proximity (indicator 6) between centres might be considered unnecessary if the population is

not evenly distributed throughout the district. The threshold distance of 12 km (indicator 4) may also be considered unnecessary if it is felt that this particular population is quite prepared to travel up to 30 km to a health centre.

Experiments 5–8 vary not only the inclusion of these two indicators, but also the weighting scheme used. In experiments 5 and 6 the average distance to the nearest centre (indicator 1) is held to be extremely important. This might be because the planners feel that the set of locations should be as efficient as possible for the population as a whole. In experiments 7 and 8 the population within 12 km of each facility (indicator 4) is felt to be the most important indicator. This may be because evidence has shown that people can only travel on foot and 12 km is the maximum distance which they would be prepared to go.

The results for the eight experiments are shown in Table 6. For each experiment the order of the options from best to worst is given. The results confirm that F is the most appropriate location

Table 5. Experiments

Experiment	Weighting scheme	Indicators included
1	All equally important	All
2	All equally important	Exclude No.6
3	All equally important	Exclude No.4
4	All equally important	Exclude Nos.6 & 4
5	Indicator No.1 = 0.50; others 0.1 each	All
6	Indicator No.1 = 0.60; others 0.1 each	Exclude No.6
7	Indicator No.4 = 0.50; others 0.1 each	All
8	Indicator No.4 = 0.60; others 0.1 each	Exclude No.6

Table 6. Results of experiments: Mpika District

Experiment	Order of options						
	Best			Worst			
1	F	D	A	C	B	E	G
2	F	D	C	A	B	E	G
3	F	D	A	B	C	E	G
4	F	D	C	A	E	B	G
5	F	D	A	C	B	E	G
6	F	D	C	A	B	E	G
7	F	D	C	A	B	G	A
8	F	D	C	A	B	G	E

to be upgraded, even under a variety of different weighting schemes.

However, this analysis has excluded data on local conditions and on inter-district utilization of health services. The emphasis has been placed on a small set of distance variables and population catchment sizes. It appears that the least satisfactory location is G, yet intuitively this may be seen as a suitable location because of its position on a major junction of two trunk roads. While D appears to be the second choice, a study of travel times would have to be undertaken to support this conclusion. Location C is among the best three and is close to the major highway system. Overall we suggest that this analysis can highlight some of the trade-offs which must be made when comparing the seven locations in this district.

Sesheke District

The base map for the Sesheke District is shown in Figure 2, and the options data are shown in

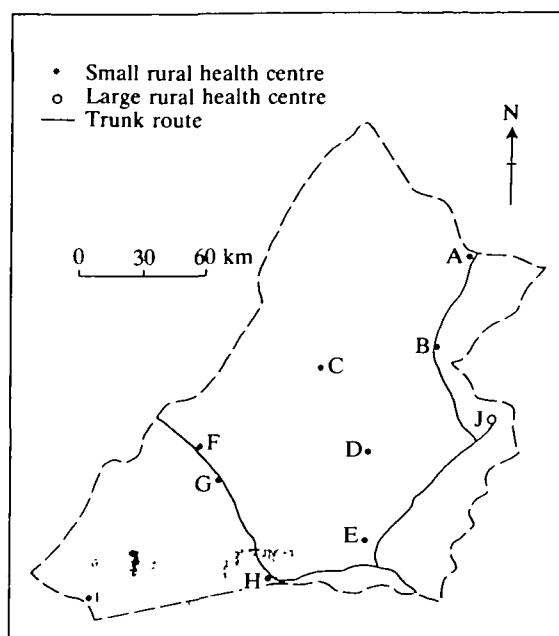
**Figure 2.** Distribution of rural health centres in Sesheke District, Western Province, Zambia, 1985

Table 7. A comparison of the 10 locations using the same six indicators is given in Table 8 and it is clear that no single option is preferred for all indicators. The largest rural centre (J) is inferior to at least two other locations for each indicator. It follows that upgrading of this facility would be at the expense of good accessibility to the potential clients.

A series of eight experiments was conducted using the same weighting schemes as for the

Table 7. Basic data: Sesheke District

		Indicators					
		1(\bar{d})	2(d_s)	3(d_m)	4(p_{12})	5(p_{30})	6(d_n)
Alternative sites	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
Benchmark		159	9	160	6000	8500	90
Optimum		min	min	min	max	max	max

Table 8. Best sites using single indicator, Sesheke District

Criteria	Best site	2nd		3rd
1	D	E		J
2	I	A		D
3	E	D	=	F
4	H	E		J
5	E	H		J
6	I	A		H=E

Table 9. Results of experiments: Sesheke District

Experiment	Order of options									
	Best					Worst				
1	E	H	B	J	I	D	C	A	G	F
2	E	H	B	J	D	C	G	I	F	A
3	E	H	J	B	I	A	D	C	F	G
4	E	H	J	B	D	F	C	G	A	I
5	E	H	B	J	I	D	C	A	G	F
6	E	H	B	J	D	C	G	I	F	A
7	H	E	B	J	I	D	C	G	A	F
8	H	E	B	J	I	D	C	G	F	A

Mpika data, and the results are given in Table 9. Out of the eight experiments it is clear that options E and H are preferred over other locations. If the population within 12 km (indicator 4) is considered to be important, then H is preferred to E. Under all the other weighting schemes it appears that E is preferred over H. For the Sesheke District either of these options appears to be close to the major road system. However, it should be noted that the existing large rural health centre, while located close to the major highway, appears to be inferior to both E and H, as well as B. Again we suggest that the method of analysis may help highlight the problems which will confront those who have to evaluate alternative locations and existing facilities if they rely on intuition alone.

Applying the model to practical situations

At the start of this paper, we argued that the model presented here provides a planning method which could avoid the pitfalls both of the approach which allows planners to come to decisions on the basis of a single criterion of their own choice (which, in practice, is very often the criterion of political expediency) and of the approach which claims to adopt

'community participation' while in fact reacting to the demands of only the most vocal and powerful groups involved. The method presented here sets up a framework in which many interest groups can be involved, and their input to the planning process at various stages be actively sought by decision-makers.

In the illustrative examples used, the criteria and options were taken as given, though their weighting was granted to be a matter for negotiation between interested parties. In reality the situation would be more complex, and there is scope for negotiation at various stages of the process.

Defining options

In the two examples from Zambia, the options were already clear. It had previously been decided that an existing rural health centre was to be upgraded, and that the decision to be made was which one to choose. In many planning situations, this is not the case. Interest groups could be brought into the planning process at this early stage, and invited to suggest alternative options. If the users are not involved at this early stage, then their later involvement in the choice between alternatives could prove to be too late because they may reject all the alternatives.

Defining criteria

In the above analysis all the criteria used were measures of accessibility. Other criteria could be included, for example the characteristics of the site itself, the availability of equipment and personnel, the existing infrastructure (e.g. roads and water and electricity supplies), the local political situation and costs. These criteria do not have to be measurable in quantifiable units; the only requirement is that for each criterion, the options available can be ranked from best to worst. It is clear that at this stage, there is plenty of scope for wide participation. The various interest groups can state which criteria they feel should be included.

Weighting criteria

Decisions have to be made as to how to weight criteria – which 'experiments' to choose in the examples discussed. This is the stage at which there is great scope for conflict between groups. Different interest groups will want to put

different weights on the various criteria. Which interest groups should be included in deciding on the weighting of criteria and how controversies between such groups should be resolved are problems that will have to be solved differently in each particular situation. Trade-offs will have to be made and how this is done is a highly political question.

The framework outlined in this paper does not, then, remove conflict and controversy from the planning procedure. What it does is to encourage the clarification of the costs and benefits of the alternatives and so enable decisions to be made in the light of a more informed debate. It also allows for the input of various groups at an early stage and throughout the planning procedure. The final decision need not rest on the power of a single interest group, nor on an intuitive assessment of the most acceptable outcome; rather, a consensus can be generated from the explicitly stated preferences of many groups whose interests might otherwise be simply seen as being incompatible and hence not capable of inclusion in the same planning process.

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