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LOCATING RURAL SOCIAL SERVICE CENTERS IN INDIA*

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This paper describes experience with application of operations research techniques in planning new roads and social service centers for the Dharampur area in India. The work involved designing a road network using a minimal spanning tree algorithm; selecting the number and location of the service centers to be constructed over a five year period using a set covering algorithm; and developing a schedule for the construction of the service centers using dynamic programming. Substantial economic benefits resulted from using the mathematical models. The experience shows that operations research models can be useful in providing an objective rationale for administrative decisions, thus playing an important role in the resolution of political conflict.

(GOVERNMENT; FACILITIES PLANNING–LOCATION; DYNAMIC AND INTEGER PROGRAMMING–APPLICATIONS)

1. Background

This paper describes the application of operations research techniques to a specific instance of regional planning. In addition to discussing the models used we also highlight some of our experiences in making these applications.

The opportunity to do the work described here arose in connection with a project aimed at drawing up a development plan for Dharampur taluka[1] in South Gujarat. The objective of the project was to produce an integrated plan of rural development aimed at the rural poor in the region [1]. Dharampur has a population of 194,000 of whom 92.5% are tribals. It is a large taluka, extending over an area of 800 sq. miles. Approximately 83% of the land is 'dungar' (hilly). About 62% of the population resides in this hilly area, while the balance is in the 'talat' (flat) area. Dharampur is a very poor taluka. A survey conducted in 1976 revealed that 85% of the population lived below the poverty line (set at Rs 60[2] monthly per capita income) and that, on the average, a person does not have food to eat for 21 days in the year.

After detailed studies, the project team identified the following factors as the major causes of poverty [2]:

(a) Poor base of resources under the control of individual families, this being characterized by undulating and to an extent rocky terrain, low water table, soil erosion and by limited farm sizes.

(b) Poor and to an extent degraded forests which occupy 43% of land and wherein 62% of the population live.

(c) Inadequate and to an extent inappropriate institutional (both official and nonofficial) efforts for development of the taluka.

(d) Sheer physical isolation of the community, particularly in the hilly areas.

To combat poverty an action plan for development was drawn up. Programs were specified in a number of areas such as soil conservation, irrigation, agriculture, animal husbandry, forestry, cottage and forest-based industries, etc. An important part of the development plan was the setting up of 'service centers' in locations dispersed over the taluka to provide minimal infrastructure, health, and education facilities. These

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[1] A taluka is an administrative unit corresponding to a county in the U.S.

[2] The current exchange rate is approximately Rs 8 to $1.

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service centers would provide agricultural extension, primary schools, public health centers, cooperative service societies, fair-price shops, and post offices. In each service center official functionaries responsible for infrastructure, health, and education facilities were to be provided residential accommodation. The functionaries to be so located were:

Village level workers,
Talatis[3],
School teachers,
Health center workers,
Cooperative Secretaries,
Post Office functionaries.

It had been observed that under the present situation the functionaries did not live near the villages where they were to work and their work places were scattered amongst several villages. These factors resulted in poor availability of functionaries to their client groups and made it difficult for the population to avail of their services. It was felt that by stationing a large number of functionaries (at least eight in each service center) in their area of service, the quality and quantity of service provided would improve substantially. Presently the chief reason that functionaries preferred to stay away from their work area was that there they had no opportunity for social interaction with their own 'types,' and also minimal facilities for education, health, and communication with towns were not available. By providing accommodation in service centers these obstacles would be overcome.

The other equally important objective of setting up service centers was to provide all villages with reasonable access to economic, educational, and health services. Thus, it was decided that service centers should be dispersed over the taluka so as to provide development services to clusters of villages within a five mile radius of each center (or at worst the walking time to a center should be about $1\frac{1}{2}$ hours). To provide infrastructure for the agricultural, animal husbandry, forestry and other programs it was also felt all-weather pucca roads connecting the service centers to the State highways should be constructed. At present the entire 'dungar' area is virtually cut off during almost 6 months in the year. Thus, the service center idea gave concrete expression to the plan's attack on items (c) and (d) listed in the causes of poverty above.

In line with the objectives of the service centers, an analysis was made to choose suitable locations. Some of the considerations in choosing a village were whether some of the required facilities were already existent, population, growth potential, proximity to highways, nature of adjoining areas, and whether the village had a 'hat.' (A 'hat' is a weekly market where tribals from nearby villages—8 to 10 miles distant—visit for selling their produce and buying consumption items such as cloth.) The analysis led to selection of 44 out of the 237 villages in the taluka for location of service centers. In addition, Dharampur, the largest town and the taluka headquarters, was already a full-fledged service center. Figure 1 gives a map of Dharampur showing existing highways and the service center locations.

Once the service centers were specified the next task was assessment of the costs involved. The construction of all the forty four service centers was estimated to cost Rs 5.5 million. In order to estimate road costs, which were expected to be sizeable, the Public Works Department (PWD) was approached. The rough estimate provided was that the cost would be about Rs 90 million covering a length of 400 miles of all-weather roads. Since the total amount available from the Tribal Sub-Plan of the

[3] Talatis are the lowest-rung officials of the State Government, responsible for administrative matters in a group of villages.

Government of Gujarat for the Five-Year Plan period was expected to be no more than Rs 130 million, it seemed that the road program would leave only an inadequate sum for irrigation, soil conservation, agriculture, forestry and other projects. It was at this stage that the first attempt at applying operations research was made.

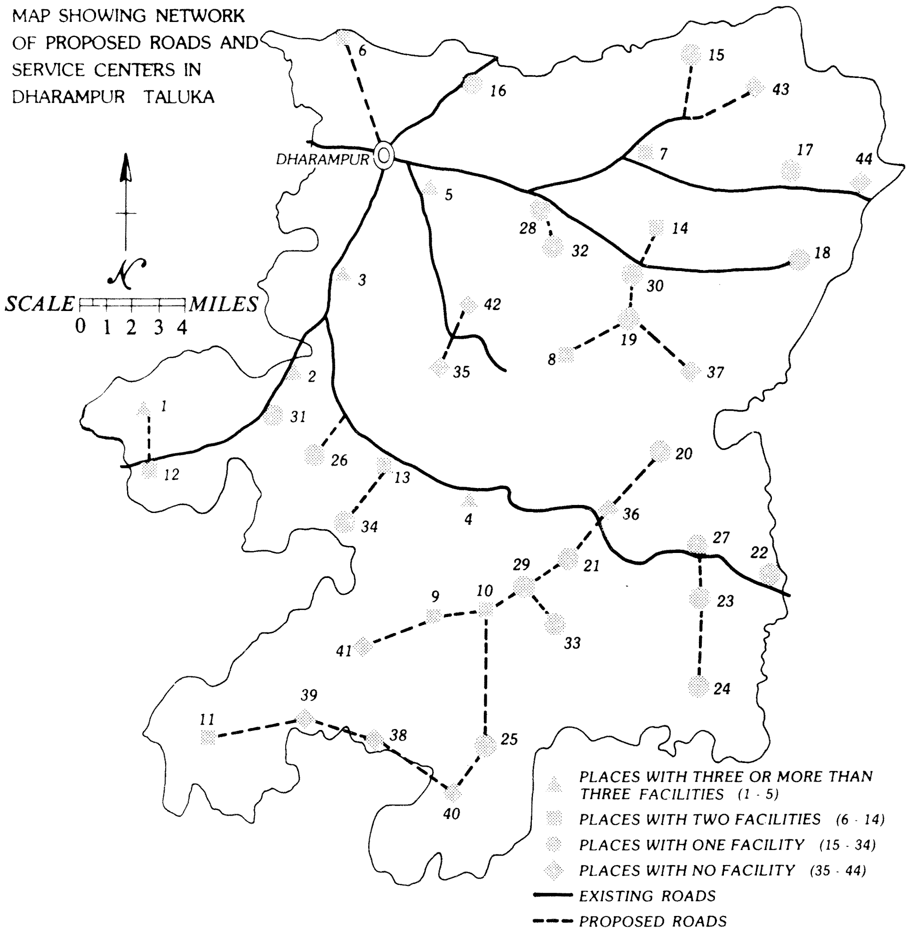

FIGURE 1. Map Showing Network of Proposed Roads and Service Centers in Dharampur Taluka.

2. Specifying a Road Network

Specifically, the problem was to find the minimum cost road network to connect the forty four service centers to the existing main highways. The minimum cost objective was chosen to save as much as possible from the Rs 130 million for projects other than the road program. The motivation for the road program was to provide year-around access to the centers. Other objectives (such as minimizing the total travel time from the villages to Dharampur), which would lead to more costly solutions, were felt to be not as important as spending the money on directly productive projects such as irrigation, soil conservation, forestry, etc.

In order to solve the problem, a simple modification of the minimal spanning tree algorithm of Kruskal [3] was employed. The only modification required was to introduce an artificial 45th node to represent the existing system of highways. The distance of this node to each of the 44 service center nodes was the shortest distance of the service center to the highway system. It is easy to see that this device would provide the optimal solution that was required. To translate shortest (Euclidean) distances between the nodes to costs it was found that a factor of 1.5 needed to be applied to shortest length to convert it to likely actual length for the kind of terrain existent in Dharampur taluka. The PWD uses this ratio in making its estimates for this region. In addition, a cost of Rs 225 thousand per mile of road was also supplied by the PWD.

The shortest-tree algorithm provided the minimum cost solution indicated in Figure 1. The total cost of Rs 19 million was substantially less than the original estimate of Rs 90 million. In fact this amount was no more than had been spent in the previous five years for road building in this region. Identification of the minimum cost network thus made it possible to employ the service center strategy, since a sufficient balance of funds was left over for the programs in irrigation, agriculture, animal husbandry, forestry, etc.

3. Locating Service Centers

After the plan was drawn up and discussed it was found that the Rs 5.5 million required for construction of service centers would not be available in the five year period as suggested in the plan. Whereas the other elements of the plan, including the road program, were assured of financial support, the sources that were to be tapped for the service center construction costs were inadequate. The amount that the planners would have available for the next five years was estimated at around Rs 1.3 to 1.4 million. Thus, although part of the objective of the service centers—namely opening up communications to villages—could be met, there was a need for reducing the number of service centers to be constructed in the next five years to be within the available budget.

A seminar was held with local leaders, voluntary workers, government officials and planners to debate this issue. Local leaders, the most vociferous of whom came from the 'talat' region, and some officials urged that service centers in the 'talat' region be given priority. Their main argument was that since many service center locations in the 'talat' region already had facilities, it would be possible to set up more service centers within the constrained budget if 'talat' locations were chosen. On the other hand, others, principally voluntary workers, argued that the objective of the plan was to improve the conditions in the poorest parts of the taluka and so remotely located service centers in the 'dungar' region should be taken up in the five year period. Ultimately, the planners decided that they should establish an objective criterion for choice of the service centers which would lead to a balanced level of services to the entire region. The criterion they chose was to minimize the maximum distance of any village from a service center subject to the budget not exceeding Rs 1.4 million. It was decided to employ an operations research model to make this choice, since an exhaustive enumeration of all combinations was infeasible (the number of combinations of service centers is $2^{44} = 1.76 \times 10^{13}$).

One can formulate the problem as specified along the following lines:

Problem (P)

$$\begin{aligned} &\text{Minimize } D \\ &\text{Subject to} \quad \sum_{j=1}^{m} c_j x_j \leqslant B \\ &\qquad\qquad\quad \operatorname*{Min}_{j \mid x_j = 1} d_{ij} \leqslant D, \quad i = 1, 2, \ldots, n, \\ &\qquad\qquad\quad x_j = 0 \ \text{ or } 1, \qquad j = 1, 2, \ldots, m, \end{aligned}$$

where m is the number of possible service center locations (45 (44 potential sites + Dharampur)),
n is the number of villages (237),
x_j = 1 if service center j is chosen,
= 0 otherwise,
B is the budget (Rs 1.4 million),
c_j is the cost of constructing service center j,
d_{ij} is the distance between village i and center j,
D is the 'service level'; i.e., the maximum distance of a village from one of the chosen service centers.

As formulated above, the problem is a difficult nonlinear integer programming problem. Hence, the problem was recast as a series of parametric problems with D, the service level, as the parameter.

For a given value of D it is possible to formulate the problem of choosing the centers with minimum total cost as a (linear) integer programming problem. This type of formulation has been used by Toregas, et al. [4], for locating emergency service facilities.

Problem (Q)

$$\begin{aligned} \text{Min} \quad & \sum_{j=1}^{m} c_j x_j \\ \text{Subject to} \quad & \sum_{j=1}^{m} a_{ij} x_j \geqslant 1, \quad i = 1, 2, \ldots, n, \\ & x_j = 0 \quad \text{or } 1, \quad j = 1, 2, \ldots, m, \end{aligned}$$

where

$$a_{ij} = \begin{cases} 1 & \text{if } d_{ij} \leqslant D, \\ 0 & \text{otherwise.} \end{cases}$$

In our case the size of the problem is 237 rows by 45 columns. This is a large integer programming problem. However, the problem has the special structure of the set covering problem of integer programming. Powerful algorithms are available to solve the set-covering problem efficiently. We used an algorithm of Lemke, Salkin, and Spielberg [5] to solve the above problem for eight values of D. The values of D chosen were 5, 5.5, 6, 6.5, 7, 8, 9, and 10 miles. To facilitate processing, a matrix generator program was written to automatically generate the constraint matrix for any specified value of D. Solution times averaged around 30 seconds per problem on an IBM 360/44 machine.

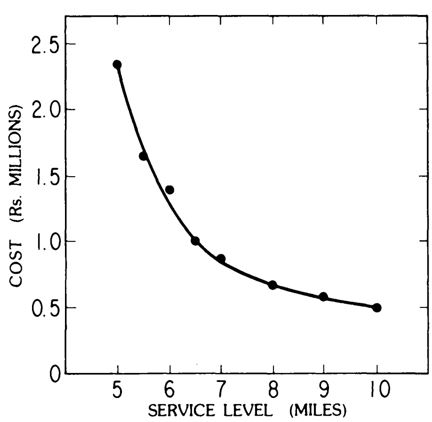

FIGURE 2. Optimal Cost for Different Service Levels.

TABLE 1

Dharampur District Service Centers

	Center	Cost (in Rs thousands)		Center	Cost (in Rs thousands)
Centers that already have 3 or more facilities	1	140	Centers that already have one facility	23	105
	2	115		24	180
	3	115		25	205
	4	80		26	180
	5	140		27	80
				28	180
Centers that already have 2 facilities	6	95		29	90
	7	180		30	80
	8	205		31	115
	9	205		32	205
	10	105		33	205
	11	80		34	105
	12	140			
	13	205	Centers that do not have any facility	35	205
	14	205		36	205
				37	205
Centers that already have one facility	15	115		38	205
	16	180		39	205
	17	105		40	205
	18	205		41	205
	19	105		42	205
	20	105		43	205
	21	205		44	205
	22	205	Dharampur (All Facilities)	45	0

TABLE 2

Table of Optimal Solutions for Different Service Levels

Service Level (Miles) (Maximum distance of a village from a service center)	Number of service centers	Budget (Rs millions)
4.5	—	not possible
5	16	2.33
5.5	13	1.65
6	11	1.39
6.5	8	0.99
7	8	0.86
8	5	0.65
9	4	0.58
10	5	0.48

The idea behind parametrizing D is to generate a curve of total cost versus D over a wide range of costs. Once such a curve is available, we can obtain the optimal solution for Problem (P) by finding the minimum value of D for the available budget from the graph, and looking up the optimal solution in Problem (Q) for that value of D.

Table 1 gives details of costs of the centers and Table 2 gives the optimal budget and optimal solutions for different values of service level. These values are graphed in Figure 2. Notice that a service level of 9 miles requires the construction of 4 centers whereas for 10 miles we have 5 centers. This seeming anomaly is due to the fact that we are minimizing cost and not the number of centers. There is a wide variation in cost from center to center (see Table 1) so that the 4 centers for 9 miles service add up to a cost of Rs 0.58 million whereas the 5 centers for 10 miles service add up to Rs 0.48 million. From Table 2 we can also see that a service level of 6 miles requires a budget of Rs 1.39 million. The optimal solution to Problem (P) was therefore taken to be the optimal solution to Problem (Q) with $D = 6$ miles.

One interesting point about the solution is that despite a slash in the budget of 75% (from Rs 5.5 million to Rs 1.4 million) and a cut in the number of centers by 75% (from 44 to 11), the service level had to be reduced by only 20%, from 5 miles to 6 miles. Expectations in the planning group had been that service would suffer much more drastically. The optimal solution balances in an equitable manner the demands made for 'talat' and 'dungar' locations: two centers are in the 'talat' region and nine centers are in the 'dungar' region. This is approximately in proportion to the total villages in each region, since 41 villages are in the 'talat' region and 196 are in the 'dungar' region.

Note that for a service level of 5 miles (the originally proposed service level), the optimal solution has a budget of Rs 2.33 million. Thus, the service level could be maintained at 5 miles while dropping the proposed budget by 58%, and the number of centers by 64% (from 44 to 16). Of course, the full benefit of all 44 centers is greater since all village functionaries will be provided residence, but from the point of view of proximity of centers to villages it is no better than a solution that costs half as much.

An interactive computer program with video-display was developed. The purpose of the program was to facilitate understanding and acceptance by decision-makers of the optimal nature of the solution arrived at by integer programming. The program showed an outline of Dharampur taluka and the 44 potential sites for service centers on the video screen. Using a teletype the user could enter the required service level and identify successively his choices for service centers. The video display drew a circle with radius equal to the service level around each choice. It also flashed the total cost of the chosen centers. Thus, the user could explore the implications of various alternative choices of service centers interactively. The program could also assist in investigation of near optimal solutions should this prove to be useful. The interactive program proved to be very valuable in convincing decision-makers of the usefulness of the mathematical approach to the problem. A number of persons connected with planning, ranging from the State's chief minister and planning minister to the district development officer and PWD engineer for Dharampur, used this program.

4. Developing a Construction Schedule

Once the service center choices for the five year plan period were determined, the next problem that needed resolution was that of phasing the construction of the centers over the five year period. Here again the problem was that each group in the taluka wanted the centers in its area of interest to be constructed first. Once more an objective criterion was sought and established. In this case the problem was balancing expenditures over time as well as balancing service levels over space. The criterion chosen was to provide the best time-averaged service level subject to the constraint that the expenditure in each year be within 10% of the average annual expenditure (Rs 277 thousand).

Dynamic programming was used to solve this problem. States were defined by an 11-dimensional Boolean vector, where a 1 in the ith element meant that the ith service center was already selected to be built, and a 0 meant that it had not yet been selected.

By using the budget constraints, all states possible at the end of t years with $t = 1, 2, 3, 4$ were enumerated. Due to the budget constraints the cumulative expenditure up to year t (Rs thousands) was restricted to fall between the following limits:

$$\text{Lower Limit} = \text{Max}[277 * 0.9t,\ 1390 - 277 * 1.1 * (5 - t)],$$

$$\text{Upper Limit} = \text{Min}[277 * 1.1t,\ 1390 - 277 * 0.9 * (5 - t)].$$

If the lower limit is violated for some year t, it either means that expenditures of less than 90% of Rs 277 thousand have been incurred in some year $T \leqslant t$, or that even spending at the maximum rate of 110% of Rs 277 thousand for all years $T > t$ will not enable a cumulative expenditure of Rs 1390 thousand at the end of 5 years. A similar argument justifies the upper limit. Using these limits it was found that only 788 out of the total of 2048 ($= 2^{11}$) states were feasible. The unique states for years 0 and 5 were $(0, 0, 0, \ldots, 0)$ and $(1, 1, 1, \ldots, 1)$ respectively. The service level for each feasible state was computed. The problem was to find the series of transitions from $t = 0$ to $t = 5$ that minimized total (and hence average) service level without violating the expenditure constraints.

A procedure was devised to further prune the network before computing this optimal path. This was done by using judgment and heuristics to identify a 'good' feasible path. This path had a total service level of 52.8 miles, or an annual average service level of 10.56 miles.

Let us define sets S_1, S_2, S_3, S_4, S_5, where S_j is the set of all possible states in year j, and let m_j be the minimum possible service level for year j; i.e. m_j is the minimum of the service levels of all states belonging to S_j.

Then, for any state $s_j \in S_j$, if the service level is l_j, the total service level for a path passing through s_j must be greater than $l_j + \sum_{i \neq j} m_i$. This gives a lower bound L which can be compared with the total service level of the 'good' path, and if $L \geqslant 52.8$, the state s_j can be deleted from S_j. This procedure enabled reduction of the number of states from 788 to 168.

After reduction, a dynamic programming routine was used to compute the optimal solution. The optimal solution had a total service level of 51.8 miles and an average annual service level of 10.36 miles. The results are presented in Table 3.

TABLE 3

Optimal Solution for Phasing the Construction of the 11 *Service Centers*

	Year 1	Year 2	Year 3	Year 4	Year 5
Centers to build	11,15,27	5,31	30,40	4,18	24,34
Service Level (Miles)	17.5	12.5	8.6	7.0	6.0
Cost (Rs 000's)	275	255	285	285	285

5. Implementation

A special committee has been set up by the state government for implementation of the Dharampur plan. The committee has decided to implement construction of the eleven centers according to the schedule presented in this paper. There is, however, a possibility that one of the centers, Fatepur (No. 11), will be substituted for by Karchod (No. 39). The reason for this is that a reservoir project has been proposed in an adjacent taluka, which would increase the risks of monsoon flooding in Fatepur. If the reservoir project is undertaken, the above substitution will be made. It is anticipated that the remaining 33 centers will be reconsidered in a later plan, probably in the five years following implementation of the plan reported in this paper. For this reason it has been decided not to revise the road program to provide minimum cost connection to the 11 centers that will be constructed in the first five years. The PWD has agreed to implement the road network so as to provide connection to the 11 centers in the next 5 years and to the remaining centers as the need arises.

6. Conclusions

The experience described here clearly shows that operations research models can be very effective tools in infrastructure planning for regional development. The savings made possible by optimization were substantial. An observation of interest regarding this study is the use of models to resolve political controversy by specification of an objective function. In this context one is really punning on the word 'objective'—it conveys the meaning of fair or impartial in addition to the usual meaning relating to desirability. Availability of models should contribute significantly to reduction of some of the oft-remarked arbitrariness of public decisions. In the absence of objective reasons for specific choices, especially of location, the administrator often finds himself overruled by powerful politicians. Politicians, sensing that the administrator has no solid basis for his specific choices, strive to replace the arbitrariness of the administrator with their own arbitrariness. Our experience shows that there is a potential for operations research models to be used to provide an objective rationale for administrative decisions, thus making them less vulnerable to the arbitrary push and pull of power politics.[4]

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