# Low-Volume Roadway Network Improvements and the Accessibility of Public Facilities in Rural Areas

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**A very important factor that affects the integrated development of rural areas is the underlying transportation network. An argument is made in this paper that the development and structure of a low-volume roadway network that serves rural areas should be coordinated with the location and accessibility of the socioeconomic services that are provided in those areas. An integrated methodology is introduced to examine the relationship between the development of the roadway network and the location of public services in rural areas. A variety of indices that measure the connectivity of the roadway network and the accessibility of public facilities are introduced. A scheme for rationalizing the improvements in low-volume roadway networks is also presented. Critical roadway segments that contribute more than others to the accessibility of the area are identified, and various improvements are suggested to increase the travel speeds on those road segments. These improvements are then evaluated in regard to the need for more locations for public facilities.**

**The methodology described in this paper is illustrated by a case study that examines the relationship between the location of health care centers and the roadway network in a rural area of Greece. The study shows that improvements in the travel times of crucial roadway segments can reduce the number of health care centers required to serve that area effectively.**

## INTRODUCTION

A major problem concerning the performance of socioeconomic services in rural and semi-urban areas of developing countries is the accessibility of these services to the population (*1*). A joint UNICEF/WHO study indicated that less than 15 percent of the rural population in some developing countries has access to primary health care services (*2*).

The accessibility of rural areas is directly related to the structure and properties of the low-volume roadway networks that serve them. Low-volume roadway networks should therefore be developed in such a way that access is provided to the socioeconomic infrastructure of rural communities. Riverson et al. (*3*) found that accessibility greatly affects both rural communities and the interaction between rural and urban areas.

The close relationship between the accessibility, socioeconomic development, and quality of low-volume roadway networks led a number of researchers to assess the investments made in the development of low-volume roadway networks within the framework of integrated rural development (*3-7*). It is to be assumed that when the economics of low-volume roads are evaluated in the context of integrated development, emphasis should not be placed on transportation economics (i.e., roadway user benefit/cost analysis), but on the broader contribution of low-volume roads to the socioeconomic development of rural areas (*4*). The improvement of low-volume road networks should not be justified solely in terms of the benefit to the roadway, but of the benefit to the entire region it serves.

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## METHODOLOGY

### Definitions

The problem of improving a low-volume, rural roadway network is based on the accessibility of public facilities in that area. For methodological purposes, a low-volume roadway network can be abstracted in the mathematical form of a graph, $G(V,L)$, where $V$ is the set of network nodes and $L$ is the set of network links. The set of the network nodes includes all the villages in the study area and the major intersections of the roadway network. Nodes are also used to separate the segments of the roadway that have different operational characteristics (Figure 1). The set of network links includes all roadway segments that connect the villages in the study area. Two important properties that define the operational quality of a transportation network are the connectivity of the network and the accessibility of the individual nodes.

The connectivity of a transportation network is defined as the degree to which all pairs of nodes of the network are interconnected (*8*). A number of indices have been developed to measure the connectivity of a transportation network; among them are 1) the alpha index, 2) the beta index, and 3) the gamma index. If $v$ is the number of nodes $|V| = v$, and $l$ is the number of links $|L| = l$, then the three indices can be defined as follows:

$$\alpha = \frac{l-v+1}{2v-5} \times 100 \qquad (1)$$

$$\beta = l/v \qquad (2)$$

$$\gamma = \frac{l}{3(v-2)} \times 100 \qquad (3)$$

The alpha index expresses the ratio of the number of circuits that exist in a network to the maximum number possible. A

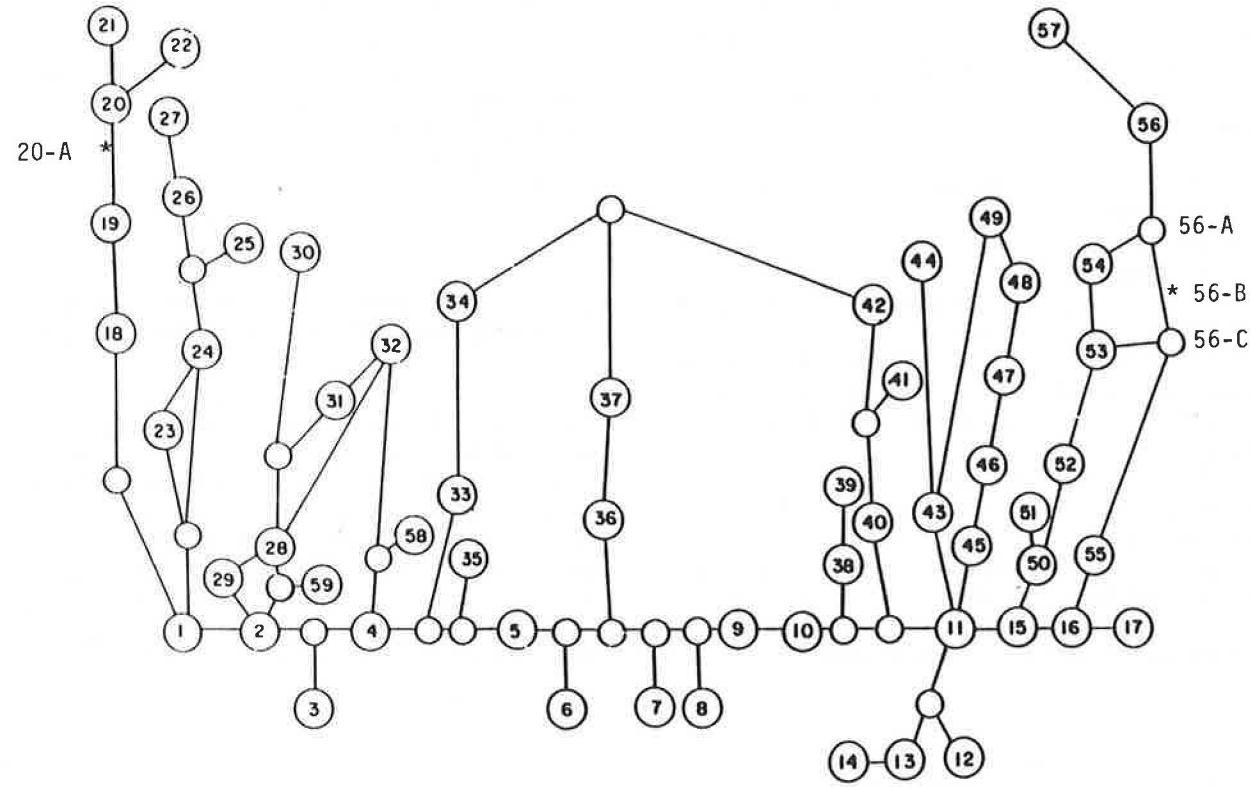


**FIGURE 1 Transportation network of the study area.**

circuit is defined as a path through a network that begins and ends at the same node without passing through any other nodes more than once. The beta index expresses the ratio of the number of links to the number of nodes to be connected. Finally, the gamma index is defined as the ratio of the number of links present to the maximum number of links that could possibly exist between a specified number of nodes. The connectivity indices provide useful aggregate information on the structure of an existing transportation network. Maximum connectivity of a transportation network is established if there is a direct link between each pair of nodes in the system. The connectivity of the network and the travel speeds of the individual links are the two factors that most affect the operational status or quality of a given transportation network.

The accessibility of public facilities in a given rural region is the central construct in the development of a methodology for selecting low-volume roadway network improvements. Two types of accessibility can be defined for nodes in a transportation network: relative and integral. The relative accessibility of a node is defined as the length of the shortest path that connects it to another node. The integral accessibility of a node is defined as the sum of the relative accessibility of one node to all other nodes of the network. Integral accessibility indicates how easy it is to reach a specific node from the entire set of other nodes in the network. The lower the value of the integral accessibility, the higher the accessibility of the node.

## Improvement Selection Scheme for Low-Volume Roads

The improvement selection scheme (ISS) for low-volume roads is based on the fact that the accessibility of a given node, or village, is a function of the travel speeds of individual links and the connectivity of the transportation network. The accessibility of the villages in turn determines the number and location of public facilities necessary to effectively service the region under study.

The number and the location of public facilities partition the overall region into sub-regions, or catchment areas, that are served by individual facilities. Once the catchment area of each individual facility is defined, the accessibility of the villages within each service area can be measured. The relative accessibility between each village in a given catchment area and the village that houses the central facility is measured by the travel time required to go from the specific village to the corresponding center. The greater the travel time, the less accessible the central facility is.

In most instances a threshold value (T) of travel time is established as a criterion to determine whether or not a village can effectively obtain services from a facility. If this threshold value is not exceeded, the location and the number of facilities established is satisfactory and the transportation network needs no improvement. If the threshold value is exceeded, which is the case in most low-density, rural road networks, then improvements should be made to the network. The goal of the improvements should be the reduction of the travel time, or relative accessibility, between the least accessible village and the central facility of each catchment area. The segments of the network on which improvements should be made can be identified by ranking the per mile contribution in travel time of each link in the path that connects the most inaccessible villages with their corresponding service facilities.

Once improvements have been made to the transportation network, the accessibility of the facilities can be reassessed. If certain villages are experiencing travel times higher than their threshold value, then more facilities should be established to cover the entire region more effectively.

The basic steps of the ISS shown in Figure 2 can be summarized as follows:

*Step 1.* Compute the connectivity of the network using Equations 1, 2, and 3.
*Step 2.* Establish a travel speed for each link of the network based on the design characteristics of the link.
*Step 3.* Find the relative accessibility of each village in regard to its corresponding service facility.
*Step 4.* Rank the relative accessibility of all villages in descending order and identify the villages that have an accessibility value, or travel time, greater than the established threshold value.
*Step 5.* Rank the most inaccessible villages in descending order and identify the paths that connect these villages with their facility centers.
*Step 6.* For each path, identify the links that contribute the most to the total travel time of existing paths. Examine the effect of improving the travel speeds of these links on the accessibility value. Calculate the associated cost.
*Step 7.* Simulate an increase in the connectivity of the network and examine its effect on the accessibility of the disadvantaged villages. Determine the corresponding cost.
*Step 8.* Determine the annual cost of building and operating an extra public facility.
*Step 9.* Compare annual costs and benefits of Steps 6, 7, and 8. Realize the strategy with the lowest annual cost. (Steps 6, 7, and 8 can be performed in any order.)

## A CASE STUDY OF LOW-VOLUME ROADWAY NETWORK IMPROVEMENT IN A RURAL AREA OF GREECE

The procedure described in the previous section was applied to identify which links in a low-volume roadway network in a rural area of Greece required improvement in regard to the location of primary health care facilities. The study area is a rural county located in the Peloponnesus region of Greece (Figure 3). It consists of 59 towns and villages that have a total population of 46,412. The settlements of the study area can be divided into three zones according to their altitude: coastal, semi-mountainous, and mountainous. Almost 75 percent of the

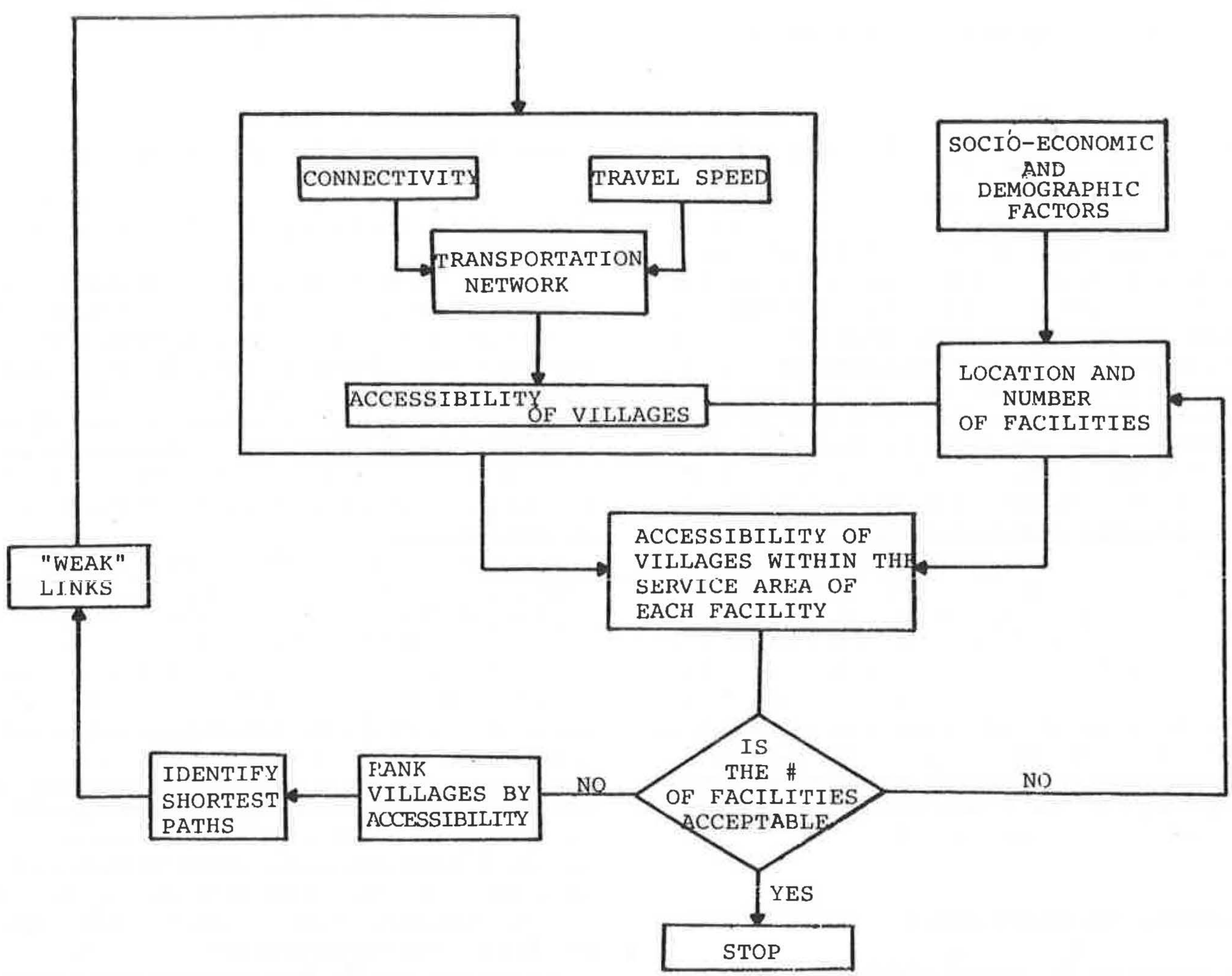


FIGURE 2 Logic of the improvement selection scheme (ISS).


**FIGURE 3 Location of the study area.**

population lives near the coastal zone and has relatively good access to the national transportation corridor that follows the coastline. The major centers of socioeconomic activity are also located near the national transportation corridor. These centers are located at Nodes 1, 5, 11, 15, and 28 (Figure 1).

### A Description of the Underlying Transportation Network

The roadway network of the study area contains links that belong to three classes of roads: national, county, and local. The main national roadway corridor runs along the coastal zone and can be represented by the sequence of links that connects Nodes 1 and 17. County and local roads connect the mountainous and semimountainous zones with the main national roadway corridor. The north-south connector roads intersect the national roadway corridor, which provides the main east-west access through the area. In terms of carrying volumes, the local roads and a substantial number of the county roads should be considered low-volume roads.

### The Location and Number of Primary Health Care Facilities

The location and number of required health care facilities was based on a travel time threshold value. The threshold value was chosen that accounted for the belief that each resident of the study area should not have to travel more than 25 min to reach the nearest health care facility. Literature on the location of health care facilities indicated that travel times between 15 and 30 min could be considered threshold values for the location of emergency medical facilities (*9,10*). The imposition of the threshold value directly affects the number of facilities to be established, as shown in Figure 4. If only one facility is established, the maximum travel time would be about 42 min. If two centers are established, the maximum travel time would be about 33 min. Finally, if three centers are established, the maximum travel time would be 31 min. The location and corresponding service areas of the facilities were determined through the use of a Multiobjective Hierarchical Locational Model. More details about the model and the factors that affect the determination of locations can be found in a report by Zografos (*1*). For the purpose of this discussion, it was assumed that two central facilities currently existed. The locations of the two health care facilities and their catchment areas are shown in Figure 5.

### Application of the Improvement Selection Scheme

The application of the ISS starts by computing the connectivity of the underlying roadway network (Step 1). The connectivity indices indicate that the connectivity of a network composed of 79 nodes and 87 links is very low, as shown:

| *Index* | *Value (%)* |
|---|---|
| $\alpha$ | 4.6 |
| $\beta$ | 1.1 |
| $\gamma$ | 37.7 |

The range of typical values for the three connectivity indices $\alpha$, $\beta$, $\gamma$, for planar networks is as follows (*11*).

*Range (%)*

$$0 \leq \alpha \leq 100$$
$$0.5 \leq \beta \leq 3.0$$
$$0 \leq \gamma \leq 100$$

The low connectivity of the existing network is also apparent from its graphic representation (i.e., the network contains very few cycles).

Each link of the transportation network was stratified according to its functional characteristics, terrain type, and passability. The roadway segments were classified as national, county, or local roads, according to the functional characteristics, whereas the terrain types of the roads were classified as mountainous, semimountainous, and flat areas. Finally, roads were classified according to whether they had good, fair, poor, or difficult passability characteristics. A Link Speed Factor (LSF) was assigned to each category of road (Step 2). The LSF is defined as the inverse of the travel speed expressed in km/hr multiplied by 60 min/hr (*9*). Therefore, a LSF of 0.60 min/km corresponds to a travel speed of 100 km/hr. The major roadway categories encountered in this study and their associated LSFs are shown in Table 1. The travel time for each link of the network was computed by multiplying the length of each link, *d*, by the LSF in order to convert the distance given in kilometers into travel time in minutes. The length of each link was obtained from a map that showed the distances between the villages of the study area.

The relative accessibility of each village to the corresponding facility center (Step 3) was calculated by using Floyd's shortest-path algorithm (*12*). The inputs required by this algorithm are the travel times of the individual links, whereas the outputs are the relative accessibility and associated paths from each village to its corresponding facility center. The relative accessibility of

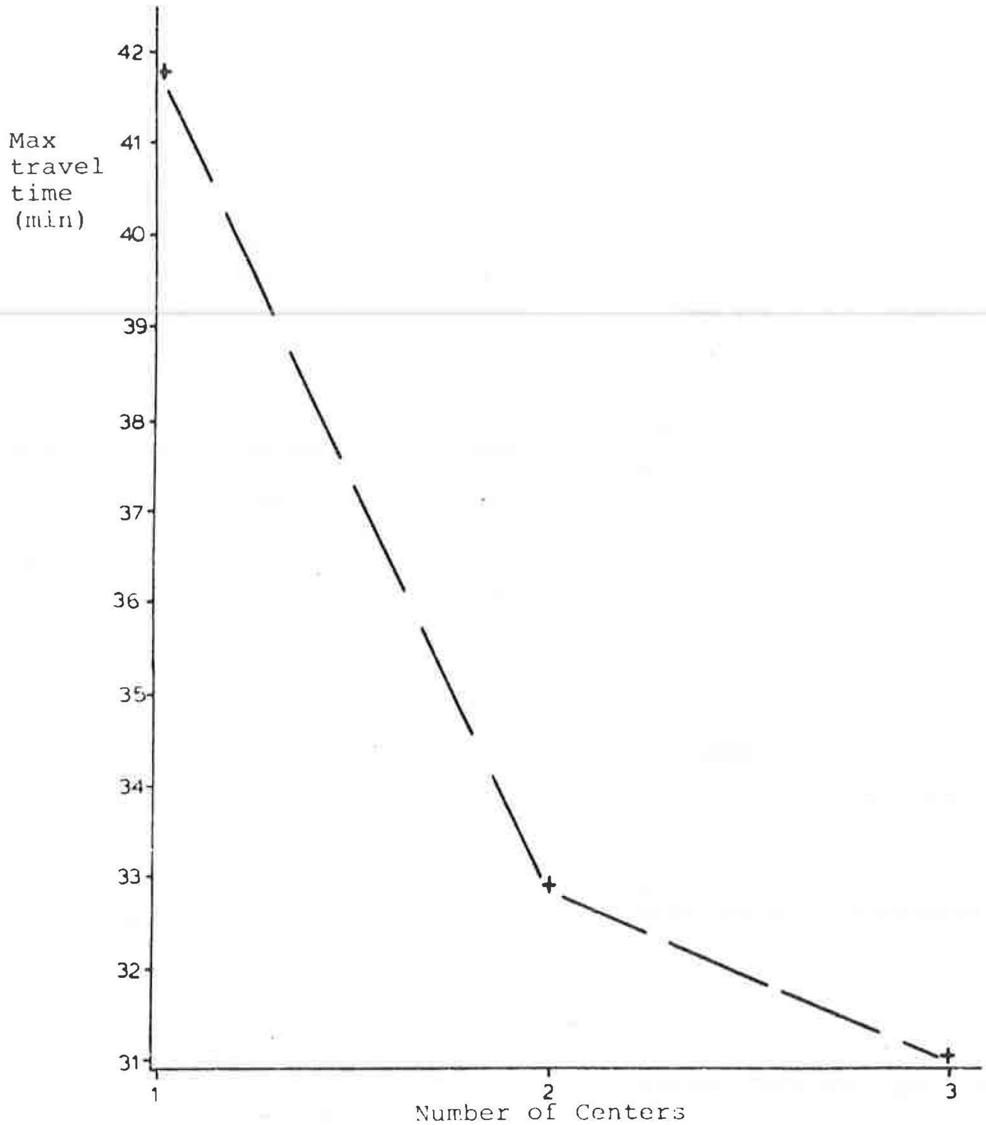


**FIGURE 4 Number of facility centers versus maximum travel time.**

each town to its corresponding facility center (Step 4) is shown in Table 2. The locations of the facilities and the allocation of villages to them were based on a threshold value of 25 min. However, this threshold value could not be achieved when the maximum number of facilities to be established was limited to two. Under the existing network, the lowest achievable threshold value is 33 min for two facilities.

The villages located at Nodes 22 and 30 were then identified as having the worst accessibility to the facility located at Node 1, whereas villages located at Nodes 56 and 57 were found to have the worst accessibility to the facility located at Node 11 (Step 5). The relative accessibility values of the most inaccessible villages to their corresponding facility centers are shown in

Low-cost connectivity improvements (Step 7) are not possible in this region because it is very difficult to construct links to connect the major branches of the network in the east-west direction. This difficulty stems from the topography of the area, in which major physical barriers are in the north-south direction. Because the connectivity of the network cannot be improved, it follows that the relative accessibility of the villages

**TABLE 1 MAJOR ROADWAY CATEGORIES ENCOUNTERED IN THE STUDY AREA**

| Network Level | Terrain Type | Passability | LSF (Min/km) |
|---|---|---|---|
| National | (F), (SM) | Good | 0.60 |
| National | (M) | Good | 0.75 |
| County | (F) | Good | 0.75 |
| County | (SM) | Good | 0.85 |
| County | (M) | Good | 1.00 |
| County | (SM) | Fair | 1.50 |
| County | (M) | Poor | 2.00 |
| Local | (F) | Good | 0.85 |
| Local | (SM) | Good | 1.00 |
| Local | (M) | Good | 1.50 |
| Local | (SM) | Poor | 2.00 |
| Local | (M) | Fair | 2.00 |
| Local | (SM), (M) | Poor to difficult | 3.00 |

LSF = Link speed factor
F = Flat
SM = Semimountainous
M = Mountainous

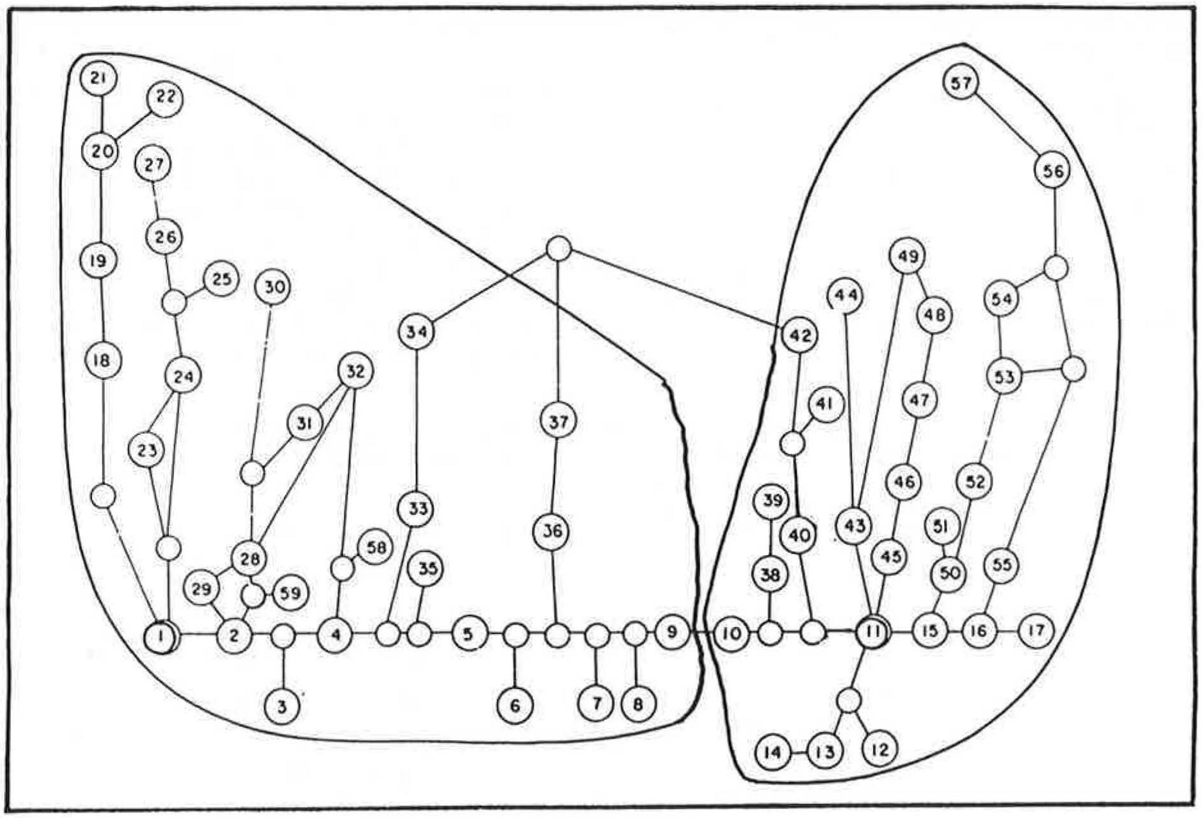

**FIGURE 5 Location of service and catchment areas of the two health care facilities.**

**TABLE 2 RELATIVE ACCESSIBILITY VALUES OF VILLAGES FROM THEIR CORRESPONDING SERVICE FACILITIES**

| Nodes Served By Facility Located at Node 1 | Relative Accessibility (Min) | Nodes Served By Facility Located at Node 1 | Relative Accessibility (Min) | Nodes Served By Facility Located at Node 11 | Relative Accessibility (Min) | Nodes Served By Facility Located at Node 11 | Relative Accessibility (Min) |
|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 30 | 25.00 | 10 | 4.30 | 52 | 6.30 |
| 2 | 1.10 | 31 | 13.90 | 11 | 0.00 | 53 | 9.60 |
| 3 | 2.30 | 32 | 11.30 | 12 | 4.00 | 54 | 11.70 |
| 4 | 5.40 | 33 | 12.80 | 13 | 4.80 | 55 | 5.50 |
| 5 | 9.70 | 34 | 13.30 | 14 | 6.80 | 56 | 25.50 |
| 6 | 18.50 | 35 | 10.00 | 15 | 1.90 | 57 | 32.90 |
| 7 | 11.50 | 36 | 17.20 | 16 | 4.30 | | |
| 8 | 13.60 | 37 | 25.00 | 17 | 4.80 | | |
| 9 | 14.00 | 58 | 6.70 | 38 | 4.50 | | |
| 18 | 7.70 | 59 | 2.10 | 39 | 7.50 | | |
| 19 | 11.40 | | | 40 | 3.30 | | |
| 20 | 15.90 | | | 41 | 8.40 | | |
| 21 | 23.60 | | | 42 | 16.30 | | |
| 22 | 29.60 | | | 43 | 4.50 | | |
| 23 | 8.20 | | | 44 | 10.50 | | |
| 24 | 8.60 | | | 45 | 4.50 | | |
| 25 | 21.10 | | | 46 | 6.50 | | |
| 26 | 13.90 | | | 47 | 9.40 | | |
| 27 | 16.30 | | | 48 | 11.70 | | |
| 28 | 3.30 | | | 49 | 16.20 | | |
| 29 | 7.10 | | | 50 | 2.30 | | |
| | | | | 51 | 3.20 | | |

can be improved by upgrading the quality of the existing low-volume network (Step 6) or adding more central facilities (Step 8).

An examination of the relationship between accessibility and the number of centers to be located revealed that the accessibility improvement was very low even when the number of facilities was increased from two to three (Step 8), as shown in Figure 4. The alternative to increasing the number of facilities is to improve the low-volume roadway network. Therefore, the next step (Step 6) is to identify which links of the network should be

**TABLE 3 NEW ACCESSIBILITY VALUES FOR THE VILLAGES MOST INACCESSIBLE TO CORRESPONDING CANDIDATE CENTERS**

| Node Number of the Most Inaccessible Villages | Nodes of Candidate Facilities* | |
|---|---|---|
| | 1 | 11 |
| 22 | 21.5 (29.6) | - |
| 30 | 17.8 (25.0) | - |
| 56 | - | 20.5 (25.5) |
| 57 | - | 24.2 (32.9) |

* Numbers in parentheses indicate old accessibility values in minutes.

improved to enhance the accessibility of the network, assuming that there are only two facilities. The links that comprise the paths that connect the most inaccessible villages with their corresponding facilities are shown in Table 4. The paths in column 3 are represented by the sequence of nodes that correspond to them. Also indicated in the table is the link that has the greatest LSF. All links with an LSF greater than 1.5 are candidates for improvement; these links are called the weak links of the network. The numbers in parentheses in the fifth column of Table 4 indicate the improved LSF of the corresponding weak links.

The links identified by Nodes 22 and 20, and 20 and 20-A, are the weak links in the accessibility of the village located at Node

**TABLE 4 THE LINK SPEED FACTORS AND TRAVEL TIMES OF THE PATHS THAT CONNECT INACCESSIBLE VILLAGES AND SERVICE FACILITIES***

| Node No. | Candidate Center | Associated Path | Length of Link (Km) | LSF (Min/km) | Travel Time (Min) |
|---|---|---|---|---|---|
| | | 22 | | | |
| | | | 4.0 | 3.0(1.8) | 12.0[6.0] |
| | | 20 | | | |
| | | | 1.1 | 1.5(1.0) | 1.7[1.1] |
| 22 | 1 | 20-A | | | |
| | | | 3.0 | 1.50(1.0) | 4.5[3.0] |
| | | 19 | | | |
| | | | 4.6 | 0.80 | 3.7 |
| | | 18 | | | |
| | | | 10.3 | 0.75 | 7.7 |
| | | 1 | | | |
| | | 30 | | | |
| | | | 14.5 | 1.50(1.0) | 21.7[14.5] |
| | | 28 | | | |
| 30 | 1 | | 2.9 | 0.75 | 2.2 |
| | | 2 | | | |
| | | | 1.7 | 0.60 | 1.1 |
| | | 1 | | | |
| | | 56 | | | |
| | | | 5.7 | 1.50(1.0) | 8.60[5.7] |
| | | 56-A | | | |
| | | | 1.7 | 1.50(1.0) | 2.60[1.7] |
| | | 56-B | | | |
| | | | 2.4 | 0.90 | 2.20 |
| 11 | 56 | 56-C | | | |
| | | | 1.5 | 2.00(1.0) | 3.0[1.5] |
| | | 53-A | | | |
| | | | 3.1 | 0.85 | 2.60 |
| | | 52 | | | |
| | | | 4.6 | 0.85 | 4.00+ |
| | | 50 | | | |
| | | | 3.5 | 0.70 | 2.50 |
| | | 11 | | | |
| | | 57 | | | |
| | | | 3.7 | 2.00(1.0) | 7.40[3.7] |
| | | 56 | | | |
| | | | 5.7 | 1.50(1.0) | 8.60[5.7] |
| | | 56-A | | | |
| | | | 1.7 | 1.50(1.0) | 2.60[10.7] |
| | | 56-B | | | |
| | | | 2.4 | 0.90 | 2.20 |
| 11 | 57 | 56-C | | | |
| | | | 1.5 | 2.00(1.0) | 3.0[1.5] |
| | | 53-A | | | |
| | | | 3.1 | 0.85 | 2.60 |
| | | 52 | | | |
| | | | 4.6 | 0.85 | 4.00+ |
| | | 50 | | | |
| | | | 3.5 | 0.70 | 2.50 |
| | | 11 | | | |

* Numbers in parentheses indicate new link speed factors; Numbers in brackets indicate new travel times.

\+ Rounded to the next integer.

22. For the same reason, the link identified by Nodes 30 and 28 is a weak link in the accessibility of the village located at Node 30. The weak links that connect villages located at Nodes 57 and 56 are also indicated in Table 4.

Improvements to the travel times of these links will also considerably improve the accessibility of the most inaccessible towns. Column six of Table 4 indicates the travel times of these links before and after improvements were made. The new accessibility values of the most inaccessible villages are shown in parentheses in Table 3. The new accessibility values of the villages located at Nodes 22 and 30 are 21.5 min and 17.8 min, respectively, whereas the new accessibility of the villages located at Nodes 56 and 57 are 20.5 min and 24.2 min, respectively. All of the improved accessibility values of the formerly inaccessible villages are now below the threshold value of 25 min; the area can therefore be covered effectively by establishing only two health care facilities instead of three.

## CONCLUSIONS

An integrated scheme for selecting and ranking improvements in a low-volume roadway network has been presented that identifies which roadway segments are contributing the most to the accessibility of villages in rural areas. Once the weak links in the system are identified, a number of improvements can be made to the specific links to increase travel speeds. The gains in accessibility of formerly inaccessible towns can be evaluated in regard to a threshold value that defines the quality of the services provided. A case study that illustrated the applicability of this method was presented; it showed that the quality of health care in a rural area can be considerably improved by increasing the travel speeds of crucial links in the low-volume roadway network.

Another finding of the study was that an increase in the number of facilities from two to three did not guarantee an improvement in the quality of health care. It was found that an investment to improve low-volume roadway networks was more effective than an investment to build more health care facilities. In the course of this study, a number of topics that require further research were identified. In particular, issues related to the accessibility of the network need to be addressed in detail. In this research the accessibility value was defined in terms of travel time on the links. This definition assumed that an adequate level of transport resources (i.e., private cars, taxis, and ambulances) were available to the community at any given time. However, certain communities had few transportation resources. In such cases, it is important to consider the accessibility in terms of the total door-to-door time, which includes not only the actual travel time to the closest health care facility but also the time spent waiting for the arrival of a transport vehicle. In this respect, the provision of roads does not solely improve the accessibility of the facilities. In a period of tightening financial constraints, rural planners need more methods of cost-benefit analysis like the one described to ensure the greatest return on their investment.

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