

Road Network Investment System for Developing Countries

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Funding for road improvements has not been able to keep pace with needs in most, if not all, developing countries. Consequently, it has become more and more necessary to develop systems for managing the road network, including the efficient programming of projects so as to make the best possible use of limited funds available. The development of models to aid investment decisions for the road sector in developing countries began to receive impetus in the late 1960s through work initiated by the World Bank. Today, such comprehensive models as the Highway Design and Maintenance Standards Model (HDM-III) are available. What is needed in addition are management systems for taking over after the basic investment decision has been made so that specific and optimal network rehabilitation and maintenance programs can be produced. A methodology in the form of the Road Network Investment System (RONIS) for establishing road investment priorities is adjustable and suitable to low-income, developing countries. The system was applied to an actual sample network of paved, gravel-surfaced, and earth roads in Sierra Leone, West Africa, to illustrate the following: determination of the present status of the network, identifying improvement needs, developing priority programs for specified funding levels, and analyses to assess the impacts of different funding levels on future serviceability of the network.

In most highway departments, funding for rehabilitation and maintenance has not been able to keep up with the improvement needs. This problem is generally more visible in developing countries. Consequently, cost-effective allocation of shrinking resources in the improvement and rehabilitation of road networks in developing countries has become particularly difficult. The desired result can be accomplished through the development and implementation of road management systems (RMSs).

The application of models to aid investment decisions for the road sector in developing countries received impetus in the late 1960s through work initiated by the International Bank for Reconstruction and Development. Today, such comprehensive models as the World Bank's Highway Design and Maintenance Standards Model (HDM) (1) and the Road Transport Investment Model (RTIM) (2) are available for this purpose. These models are products of a large amount of experimental and analytical work incorporating four environments: Kenya, Brazil, Caribbean, and India. However, the models are essentially directed to decision making for overall road investments. In their simplest forms, the models are used to minimize the total cost of transportation over the life of either one road link or an entire network.

A major issue in the use of these systems in developing countries is the lack of a comprehensive priority subsystem as a program and financial planning tool. The primary functions of such a tool include determination of the network status at various points in time, improvement needs, and evaluation of different policies on a short-term but detailed basis within the context of the network level of management.

After the basic investment decision has been supported by the HDM or RTIM models, there is a real need for a system to then take over and produce specific optimal programs and financial planning lists at the network level. In order to detail improvement needs, to group them into viable projects, and to produce a refined budget and program of works, such a system would require performance prediction models that suit the needs of growing databases in developing countries. The current condition of a road will be the key input data for performance prediction.

A simple, practical, and yet comprehensive system for programming and planning network improvements both for unpaved and paved road sectors in low-income developing countries is described. An illustration of the use and general applicability of the procedure is provided through a case application in Sierra Leone, West Africa.

THE ROAD NETWORK INVESTMENT SYSTEM (RONIS)—AN OVERVIEW

RONIS, which is a menu-driven, user-friendly, microcomputer-based software system, incorporates three major modules, as shown in Figure 1.

Input Data and Candidate Analysis Module (ICAM)

The first module, ICAM, starts with inventory of the road sections. These inventory data, involving structural and surface condition, traffic volume, road geometrics, etc., are used to establish the present status of each road section. A road deterioration (performance prediction) model is then applied to predict their remaining service lives. The output of this phase consists of a list of sections that are candidates for improvements.

Economic Analysis Module (ECAM)

The second module, ECAM, concerns detailed economic analysis. It considers those sections that are estimated to have

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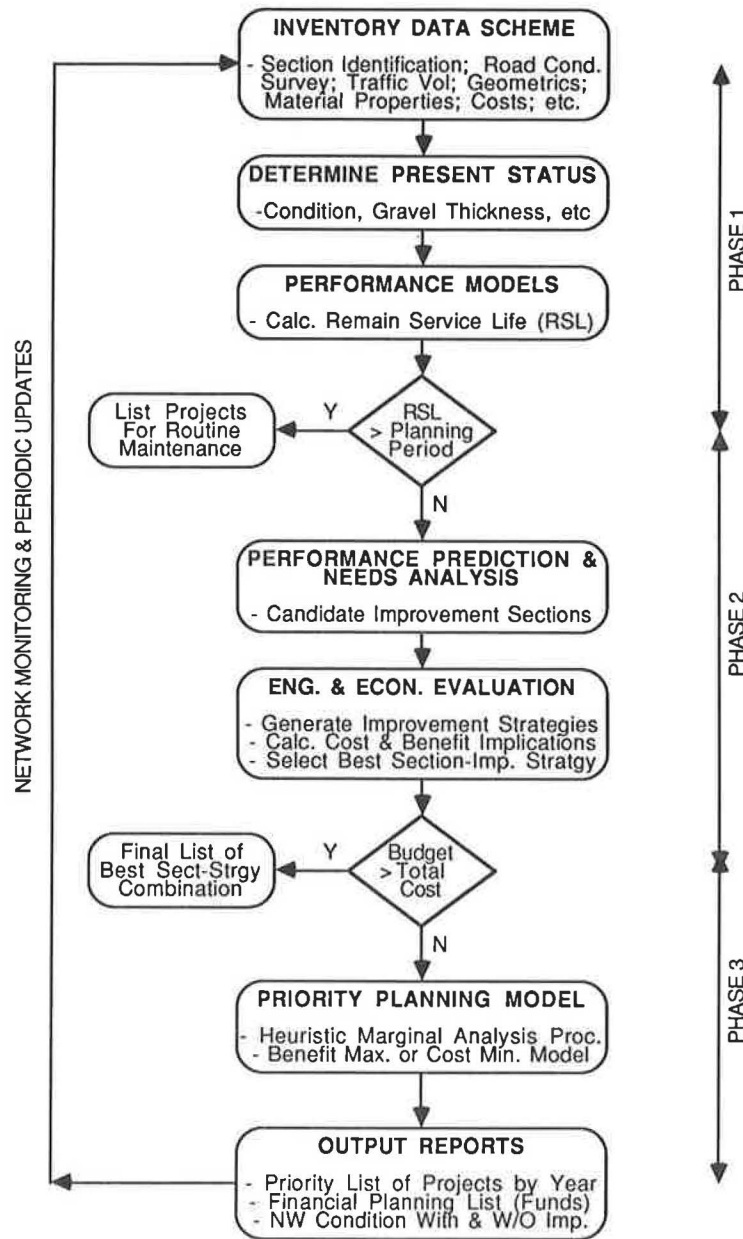


FIGURE 1 General structure of RONIS.

a remaining service life less than the planning period. At the end of the remaining service life (i.e., needs year), several surface improvement strategies are generated. Four strategies for paved roads (do nothing, single overlay, double overlay, and reconstruction) and three strategies for graveling (lifts of 5, 10 and 15 cm) for unpaved roads, and the possibility of paving of unpaved roads, are considered.

Performance is predicted and the economic implications are calculated for each strategy. In other words, costs related to improving the road and benefits (i.e., savings in vehicle operating costs because of the improved road condition) are calculated.

The output of this phase is a list of candidate sections, alternatives and their direct costs to the agency, and user

benefits for each possible implementation year in the planning period.

Heuristic Analysis Module (HAM)

The final module, HAM, uses the outputs of ICAM and ECAM as inputs in a priority programming model. HAM is a near-optimization model that establishes priorities over the whole network on the basis of benefit maximization and budget constraints. It also recommends an optimum improvement strategy for each road section considered in the analysis.

The final output of the system is an optimum rehabilitation strategy and implementation year for each project. It is based

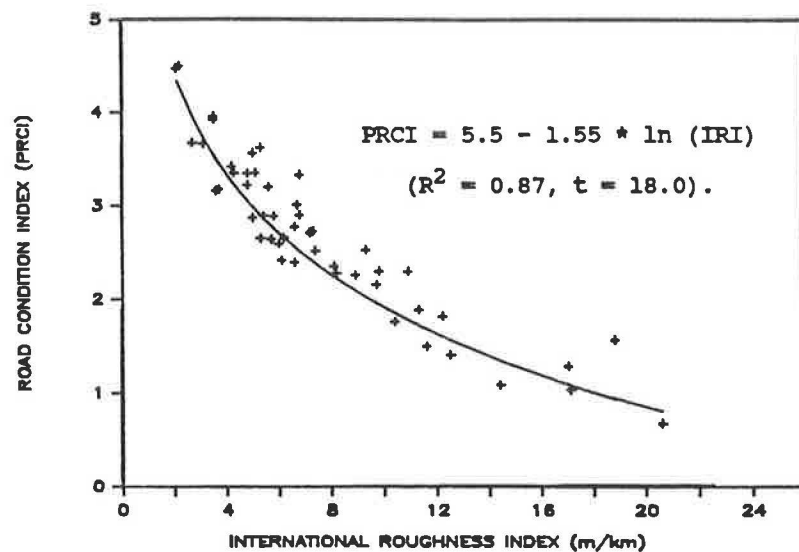


FIGURE 2 Relationship between serviceability and road roughness.

on the maximization of net annual worth (NAW) and at the same time ensures that the agency will stay within its budget in each year throughout the planning period.

RONIS incorporates four major concepts; serviceability of a road, performance prediction models, economic evaluation, and priority analysis, which are further discussed in the following section.

DEVELOPMENT OF A SERVICEABILITY MODEL

The serviceability of a road is an essential element in the development of RMSs. Serviceability is needed to define the present status of road sections in order to locate abnormal changes and deficiencies, and thereby identify improvement needs. In addition, serviceability is required to describe the life history of a road for the evaluation of alternative improvement strategies and to establish a system-wide basis for allocation of road improvement resources.

In the practical use of the serviceability concept, if the roughness of a road section is measured mechanically, the road user's response can be estimated in terms of a serviceability index.

The data base used for developing the serviceability model is taken from Brazil's International Road Roughness Experiment (IRRE) study (3). The data matrix consists of 18 raters and 49 road sections varying from earth to asphalt concrete roads. The rating results were analyzed to see if any systematic error was involved in the ratings using the procedures described by Hutchinson (4). Several models were hypothesized; the recommended one is shown in Figure 2.

PERFORMANCE PREDICTION MODELS

Performance is a general term for how roads change their condition or serve their intended functions with accumulating use of traffic and environment (i.e., over time). One of the most useful approaches, particularly in developing countries

where historical data are limited, involves the development of a model based on the current state of the road.

Performance of Unpaved Roads

The deterioration of unpaved roads is characterized primarily by roughness and gravel loss. Other useful measures, such as rut depth, are not explicitly taken into account because their effects are subsumed in the property of roughness along the wheel paths.

Blading Frequency Model

Road roughness increases with time through the continuous action of traffic and alternating seasonal effects. At high roughness levels, a blading operation is undertaken to smooth the surface and potholes. Hence, a sound blading policy is the most important first step in prolonging the life of unpaved roads. An objective way is to blade the road often enough to ensure levels of roughness that minimize the sum of vehicle operation and blading costs. Data from several sources in developing countries (5-7) have been used to develop a regression-based model between blading frequency and daily traffic volume.

Figure 3 indicates a minimum of one blading per year for roads carrying less than 50 vehicles per day; and six to eight bladings for high-traffic volumes. Consequently, although Figure 3 is based on a limited sample size, it can be used as a first estimate in most regions. Because of differences in materials and economic circumstances, caution should be exercised in generalizing these findings without more comprehensive local field studies.

Graveling Operation Model

Predicting the loss of gravel material is important in defining the present status of a road and in planning future graveling

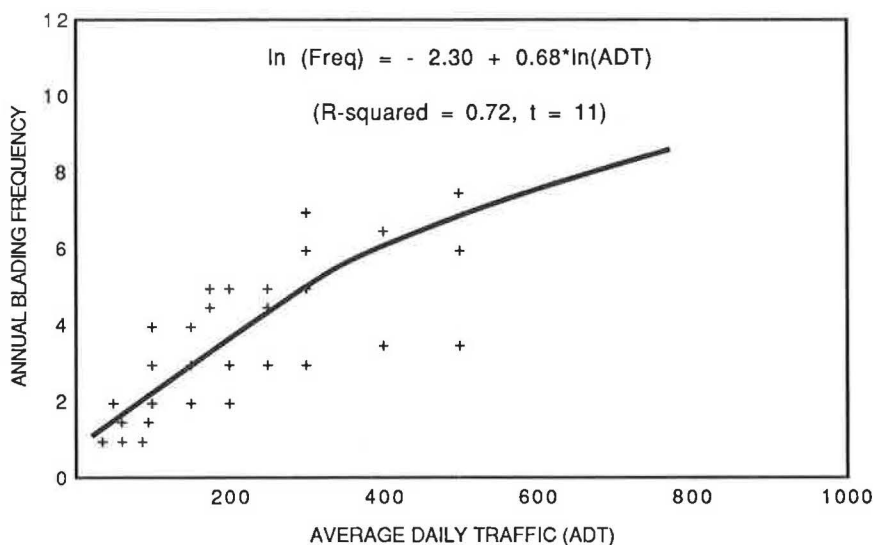


FIGURE 3 The effect of traffic volume on the annual blading frequency.

operations. An agency needs to know when to program such operations for the entire network. A recursive model is formulated of the form

$$G_t = G_0 - k * t \quad (1)$$

where

- G_t = Gravel thickness (mm) at any time t ,
- G_0 = Present gravel thickness (mm),
- k = Annual gravel loss (mm), and
- t = Period between observations (years).

Visser's gravel loss model (8) is used as an initial basis for estimating the k values for different classes of roads. Road sections having similar characteristics (e.g., surface type, traffic, and geometrics) can be grouped into classes. The implicit assumption in the use of road class is that a change in the level of each factor will result in a significant change in the loss of surface material.

Three levels of traffic (low, medium, and high); three levels of terrain (flat, rolling, and steep); and one surface material (lateritic gravel) have been considered, as presented in Table 1. Each class of road is defined by the combination of each of these factors.

The k values in Table 1 are class dependent. Horizontal curvature has a minor effect. Those responsible for graveling want to know the frequency in terms of years rather than months. An average radius of curvature is 400 m, which reflects typical design standards of unpaved roads.

Performance of Paved Roads

A useful approach in predicting pavement performance, particularly when historical data are limited, involves the Markov method. This approach captures the knowledge and experience of local engineers, superintendents, and technicians for predicting changes in road condition with time for various

combinations of traffic, layer types and thickness, and sub-grade strength. Details of the use of Markov modeling procedures have been described by Karan and Haas (9) and by Turay (10).

The essential requirements of the Markov chain model include the definition of pavement states, pavement classes, initial state vector, and transition matrices. Subjective opinions of five pavement engineers from Sierra Leone have been used to develop the initial transition matrices for 12 road classes (see Table 2), as described by Turay (10). This procedure was used because of unavailability of detailed field inventory data.

The flexibility and ease of the Markov approach make it appropriate for transfer from one country to another, particularly for situations in low-income countries. Figure 4 gives typical performance curves for three of the road classes from Table 2 under a do nothing strategy.

ENGINEERING ECONOMIC ANALYSIS

In most RMSs, detailed cost analyses are necessary for in-depth project evaluation. At the network level, however, average or benchmark cost information may be considered adequate for priority analysis, as shown in Table 3 for Sierra Leone conditions.

User benefits are defined as savings in vehicle operating costs (VOCs) caused by improving the road's condition. The reason for selecting this criterion is two-fold. Technically, major road cost studies have conclusively shown that VOC, which is the largest component of the total life cycle cost of roads in developing countries, is extremely sensitive to variations in road roughness (1,2,11).

From a national viewpoint, developing countries have always emphasized the economics of road transport because of the influence of international development agencies, which require that every project be economically justified before lending money to the bank-assisted countries.

Therefore, the introduction of benefits that are defined as savings in VOCs make the evaluation more practical and above

TABLE 1 PERFORMANCE FACTORS AND ANNUAL GRAVEL LOSS VALUES OF CLASSES OF UNPAVED ROADS

| CLASS OF ROAD | TRAFFIC VOLUME (ADT) | TYPE OF TERRAIN | ANNUAL GRAVEL LOSS (k), cm | | |
|---------------|----------------------|-----------------|----------------------------|-----|-----|
| | | | RADIUS OF CURVATURE (m) | | |
| | | | 300 | 400 | 500 |
| 1 | Low | Flat | 1.4 | 1.3 | 1.2 |
| 2 | Low | Rolling | 1.7 | 1.6 | 1.5 |
| 3 | Low | Steep | 2.0 | 1.9 | 1.8 |
| 4 | Medium | Flat | 1.8 | 1.7 | 1.6 |
| 5 | Medium | Rolling | 2.0 | 1.9 | 1.8 |
| 6 | Medium | Steep | 2.4 | 2.3 | 2.2 |
| 7 | High | Flat | 2.5 | 2.4 | 2.2 |
| 8 | High | Rolling | 2.8 | 2.7 | 2.6 |
| 9 | High | Steep | 3.2 | 3.0 | 2.9 |

| PERFORMANCE FACTOR | DESCRIPTION |
|---------------------|--|
| Traffic Level (ADT) | Low < 100; 100 < Med. < 300; High > 300. |
| Traffic Mix | 20 % cars; 50 % light vans; 30 % trucks |
| Terrain Type (%) | Flat < 2; 2 < Rolling < 5; Steep > 5. |
| Surfacing Material | Laterite Gravel: < 10 P.I., < 20 % pass. 0.074 mm. |
| Environment/Climate | 6 months each - wet and dry seasons; Avg. annual temp = 28 deg. C., Rainfall = 200 cm/yr. |

all make it possible to compare surface improvement projects with other competing transportation demands.

The Kenya VOC relationships (11) were selected because the corresponding VOC components could easily be estimated as a function of road roughness, bypassing all intermediate steps requiring estimation of road geometrics, vehicle dynamics, etc. This is a major advantage because the focus of RONIS is on improving the surface condition of road networks.

The basis for economic evaluation is the NAW method. Of course, the benefits must exceed costs if a project is to be justified on economic grounds. For unlimited funding, the best section and strategy combination is selected. For limited funding, as is always almost the case, a priority subsystem is needed.

PRIORITY PLANNING MODEL

There are two main approaches for tackling the management problem of optimization of resources. The first approach can be summarized as selecting projects in such a way as to maximize the total benefits accrued from improving the road without violating the resource constraints. This approach is strictly a program planning model. The second approach can be summarized as selecting projects in such a way as to minimize road improvement expenditures subject to prespecified per-

formance levels. This approach is generally referred to as the financial planning version of road management.

These two optimization approaches represent the limits from "do the best for the road network" to "do the best for the road-using public." A compromise can be made by selecting a program planning model, and then determining the average condition of the network before and after the investment decisions are made. In effect, this process should take into consideration the importance of both the road user and the effect of the plan on the performance of the road network.

A heuristic, marginal NAW procedure has been used (10) that proceeds in three main stages. First, an initial allocation routine assigns candidate road sections to their need years. The routine maintenance budget is deducted from the total budget to allocate the budget required for major surface improvements. Marginal analysis is then applied to select the best improvement strategy for each road section, given the required budget for that year. If the list produced by this allocation routine is feasible within prespecified tolerances of the budget (e.g., ± 5 percent), it is the optimal solution.

The second stage, which involves a reallocation routine, displaces candidate road sections by years to satisfy the budget constraints. In this procedure, some road sections may get advanced or delayed. They may even be pushed over the end of the planning period, which in practice means that they will not be improved within the planning period.

TABLE 2 PERFORMANCE FACTORS OF CLASSES OF PAVED ROADS

| CLASS OF ROAD | TRAFFIC VOL (AADT) | SURFACE THICKNESS | SUBGRADE STRENGTH |
|---------------|--------------------|-------------------|-------------------|
| 1 | High | Thick | Strong |
| 2 | High | Thin | Strong |
| 3 | High | Thick | Weak |
| 4 | High | Thin | Weak |
| 5 | Medium | Thick | Strong |
| 6 | Medium | Thin | Strong |
| 7 | Medium | Thick | Weak |
| 8 | Medium | Thin | Weak |
| 9 | Low | Thick | Strong |
| 10 | Low | Thin | Strong |
| 11 | Low | Thick | Weak |
| 12 | Low | Thin | Weak |

| PERFORMANCE FACTOR | DESCRIPTION |
|------------------------|---|
| Traffic Level (AADT) | Low < 500; 500 < Med < 1500; High > 1500. |
| Traffic Mix | 20 % cars; 50 % light vans; 30 % trucks |
| Pavement Type | Flexible (Asphalt Concrete). |
| Surface Thickness (cm) | Thin < 5.0; Thick > 5.0. |
| Subgrade Type | Strong - Granular (CBR > 12); Weak - Clay. |
| Environment/Climate | Avg. Temp. = 28 deg. C/yr., Rainfall = 200 cm/yr. |

The final stage of the procedure estimates, for each year, the average condition of the network that would result from the implementation of the priority list (including that of zero capital funds or do nothing). This added information is useful in recommending a financial plan on the basis of desired road performance levels.

SAMPLE APPLICATION

The system was applied to an actual sample network in Sierra Leone involving 80 sections consisting of 35 paved roads, 30 gravel roads, and 15 earth roads, totaling about 700 km (center line). Detailed input data for each section [e.g., location,

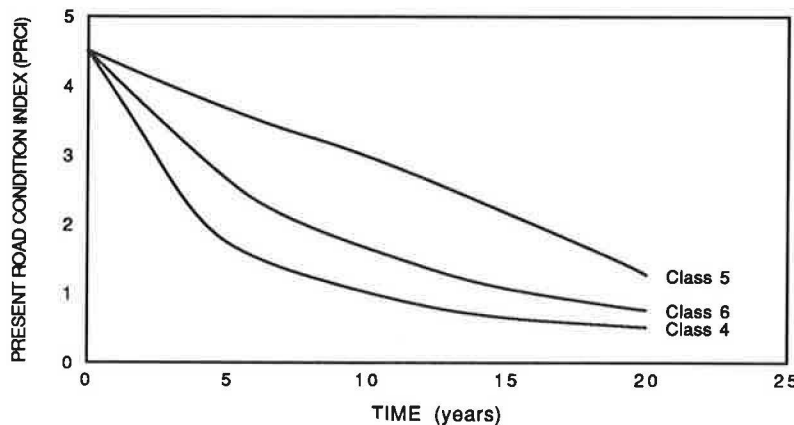


FIGURE 4 Typical performance curves under a do nothing policy.

TABLE 3 TYPICAL BENCHMARK ROAD IMPROVEMENT COSTS

| UNPAVED ROADS | | PAVED ROADS | |
|---------------|--------------|--------------------------------|-------------------|
| Activity | Cost (\$/km) | Activity | Cost (\$/lane km) |
| Light Blading | 150 | Single Overlay (Resealing) | 12,000 |
| Heavy Blading | 300 | Double Overlay (Strengthening) | 19,000 |
| Graveling | 9/cu. meter | | |
| Paving | 24,000 | Reconstruction (Restoration) | 50,000 |

length, annual average daily traffic (AADT), present road condition index (PRCI), roughness, last improvement strategy, lane width, subgrade type, grade, and gravel or surface thickness have been provided by Turay (10)].

In order to conduct the analysis, the following assumptions were used:

1. A minimum acceptable PRCI level of 2.0 was used for paved roads. Thus, a section that had a PRCI of 2.0 or less was identified as requiring a major improvement in the year.
2. A critical thickness of 7.5 cm for gravel roads was used in the analysis. A bidirectional, threshold traffic volume of 75 vehicles per day (vpd) is used as a screening device for upgrading (or graveling) an earth road.
3. A road section is considered in the optimization process starting only from the year in which it first reaches its terminal level. Once the road reaches its terminal level, it is kept at that level with a penalty cost until major improvement is scheduled.
4. A planning period of 5 years was selected to truly represent the National Development Plans of most developing countries. Also, a discount rate of 10 percent is used.

Present Status of Network

Figure 5 shows the distribution of the key performance parameter defining the status of each road sector. For the total sample network of 700 km (center line), the paved sector represents about 45 percent and has a mean PRCI level of 3.0; gravel roads constitute 35 percent with a mean thickness of 10 cm; and earth roads constitute 20 percent with a mean bidirectional traffic volume of 60 vpd. In these examples, all mean values are weighted by the total length for each surface type.

Improvement Needs

The needs year is the point in time at which the performance curve for a particular road section reaches its terminal acceptable level. Figure 6 shows the distribution of needs for the example network over a 5-year planning period.

Under a do nothing policy, a total of 63 out of 80 sections become needs for the 5-year plan. In Year 0 (i.e., present

needs), for example, three paved roads representing 4 percent of the entire network; nine gravel roads representing 10 percent of the network; and two earth roads representing 3 percent of the network are expected to become needs.

Priority Planning Results

The needs list in the previous section would have been the priority list if unlimited funds were available. However, under budgetary constraints, as is always almost the case in developing countries, some projects cannot be built in the year in which they require improvements. They may have to be delayed in time or not scheduled for rehabilitation at all, depending on the funds available.

Priority analyses were carried out for several budget levels. Table 4 presents a typical detailed, section-by-section list (for a budget level of \$3.25 million annually) that results from the analyses. Figures 7 and 8 show a summary distribution of the recommended priority list for a budget level of \$3.25 million per year for a 5-year period. Spending priorities are given to routine maintenance before allocating extra funds to major improvements activities.

The reconstruction strategy does not show up in the priority list because all projects having a negative value of NAW (i.e., uneconomical feasible projects) are deleted from further priority analysis. This policy, in effect, reinforces the notion that roads should not be allowed to deteriorate into poor condition, which requires far more costly reconstruction and lower marginal benefits compared to other improvement alternatives.

Budget Level Analysis

A summary of the long-term effects of different spending decisions is shown in Figures 9 and 10. For example, an annual budget of \$2.5 million would allow the paved-road sector to drop only slightly from its current average PRCI level of 3.0; but nearly 50 percent of these roads would become deficient by the end of the planning period (Figure 9). For the gravel-surfaced roads (see Figure 10), an annual funding level of \$2.5 million would allow the average gravel thickness to stay at about 10 cm, and the deficient mileage to drop near zero. However, the sensitivity to funding level is quite apparent in Figure 10 in that a lower annual budget would lead to a dramatic rise in deficient mileage.

For comparative purposes, a spending decision of zero capital budget (i.e., apply only routine maintenance) has been included in Figures 9 and 10 to show its extreme effects on the network as a whole. An additional impact of such an action would be significantly higher user and maintenance costs and the likelihood of losing much of the existing investments (i.e., complete reconstruction would eventually be required).

Several funding levels were also used to test the sensitivity of the system to various decision variables. Inspection of Figure 11a reveals that the number of sections in the priority list increases with increased funding. For example, 16 paved and 32 unpaved sections will be the recommended improvement priorities if a budget level of \$2.5 million per year is allocated to the network. At \$3.25 million annually, on the other hand, all needs sections (i.e., 31 paved and 32 unpaved sections)

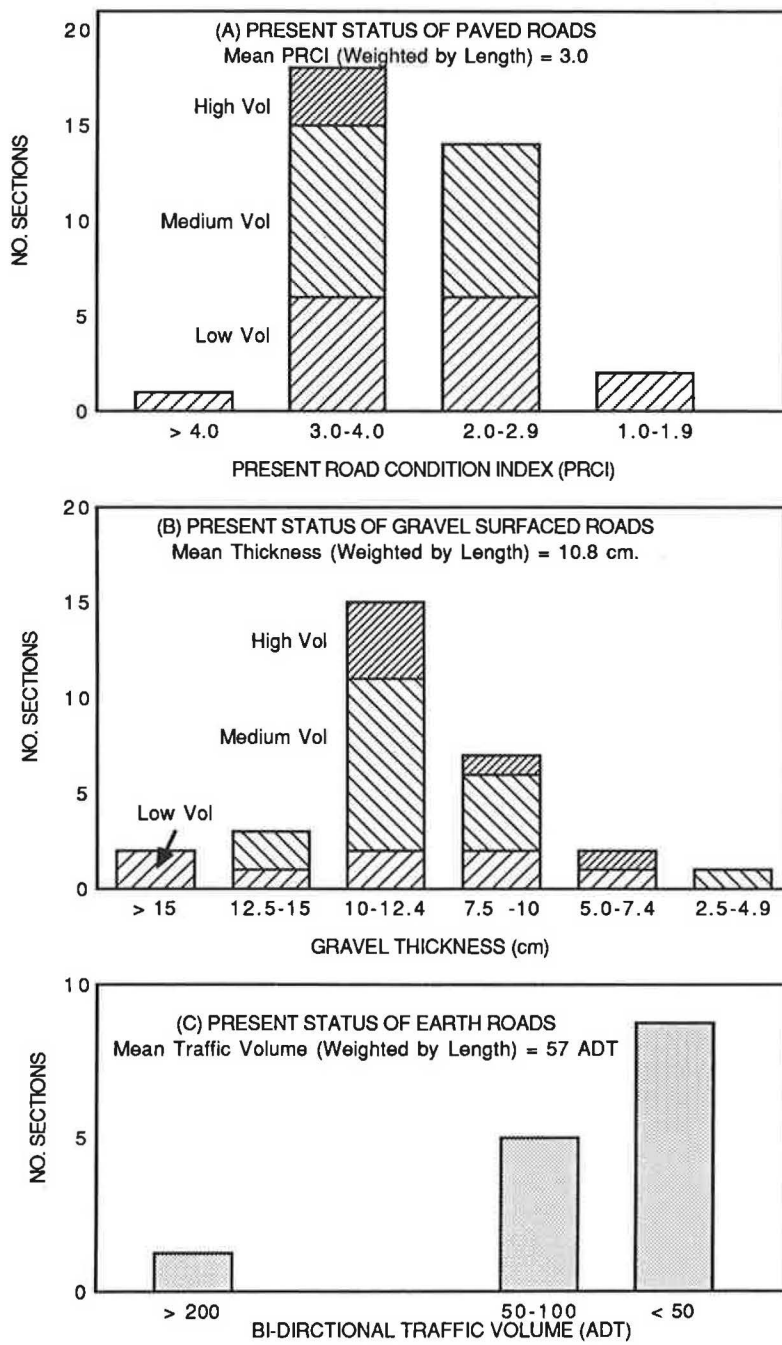


FIGURE 5 Present status distribution for a regional network in Sierra Leone.

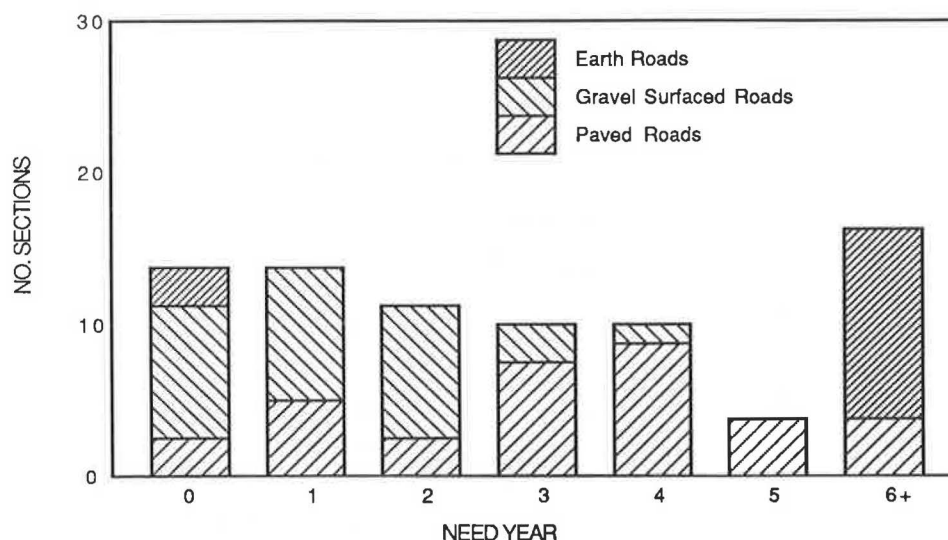


FIGURE 6 Distribution of need sections for the example network.

are considered for improvements. However, at some point, increasing the budget level does not significantly change the priority list. Spending beyond this point would represent an inefficient use of funds.

Figure 11b shows the average network condition at the end of the planning period. The plots reach an asymptotic PRCI level of 3.5 for paved roads and a thickness of 12 cm for the unpaved sector at a funding level of \$3.5 million annually. But there is little difference in going from \$2.5 to \$3.5 million annually. Also, in Figure 11c, the value of the objective function (i.e., NAW) increases substantially up to about \$3.0 million annually, and then only slightly after that, to approximate a steady state between annual funding levels of \$3.0 and \$3.5 million.

The foregoing analysis suggests that the annual funding level should be at least \$2.5 million for this network but that \$3.0 million annually is a level most advantageous to the sustained performance of the roads, highway department, and the road-using public. This type of analysis provides an objective tool for senior highway administrators to justify their budget requests and to demonstrate the consequences of reduced funding on the average condition of the entire network.

SUMMARY

A management system is presented for evaluating road network improvements in developing countries. It is compli-

mentary to basic investment decision models such as the World Bank's HDM-111. The examples indicate how the concepts of pavement management can be used to provide an objective and systematic means for planning and justifying road improvement expenditures in developing countries.

A heuristic model for optimization of available resources in developing countries is simple and cost-efficient. It can easily be implemented in a microcomputer environment. The procedure is comprehensive in that it uses a marginal analysis approach that yields a near-optimal solution. The limitation of not obtaining a strict global optimality has been traded off against practicality and the efficient use of computer resources.

RONIS can assist developing countries in answering a number of questions, including the following:

1. What is the present condition of the network and what will it become if a particular funding level is selected?
2. What sections need improvement, when is the work going to be scheduled, and how should the work be done?
3. What is the justification of increased funding or the consequences of reduced funding decisions?

RONIS provides sufficient information for determining the optimal funding level as well as establishing a premise for setting performance standards for low funding situations. RONIS allows highway authorities not only to justify a proposed funding plan but also to set funding levels on particular networks.

TABLE 4 A DETAILED PRIORITY LIST FOR AN ANNUAL FUNDING LEVEL OF \$3.25 MILLION

| RECOMMENDED PRIORITY LIST FOR YEAR 1 | | | | | | | | |
|--------------------------------------|--------|-----------|---------|----------------|--------------------|--------------------|-----------|--------------------------|
| ROAD NAME | TYPE | FROM (km) | TO (km) | TRAFFIC VOLUME | IMPROVEMENT POLICY | IMP. COST (\$1000) | NEED YEAR | OTHER YR. TO IMPROVE RD. |
| Hill St. - Hastings | Paved | 7.5 | 15.5 | 240 | Single Overlay | 192 | 1 | |
| | Paved | 15.5 | 24.5 | 200 | Single Overlay | 216 | 1 | |
| Kambia - Madina | Gravel | 9.5 | 18.5 | 200 | 5 cm Gravel | 25 | 1 | 2 (10); 5 (5) |
| Kambia - Pamlap | Gravel | 39.0 | 45.0 | 500 | 5 cm Gravel | 18 | 1 | 2 (10)* |
| | Gravel | 31.5 | 39.0 | 500 | 5 cm Gravel | 23 | 1 | 2 (10); 5 (5) |
| Lungi - Mahera | Paved | 17.8 | 23.3 | 150 | Single Overlay | 228 | 1 | |
| | Paved | 27.3 | 37.7 | 150 | Single Overlay | 250 | 1 | |

| RECOMMENDED PRIORITY LIST FOR YEAR 2 | | | | | | | | |
|--------------------------------------|--------|-----------|---------|----------------|--------------------|--------------------|-----------|--------------------------|
| ROAD NAME | TYPE | FROM (km) | TO (km) | TRAFFIC VOLUME | IMPROVEMENT POLICY | IMP. COST (\$1000) | NEED YEAR | OTHER YR. TO IMPROVE RD. |
| Hill St. - Hastings | Paved | 24.5 | 33.5 | 100 | Single Overlay | 192 | 2 | |
| Kambia - Madina | Gravel | 0 | 9.5 | 200 | 10 cm Gravel | 57 | 2 | |
| | Gravel | 18.5 | 28.5 | 120 | 5 cm Gravel | 30 | 2 | 5 (5) |
| | Gravel | 28.5 | 37.0 | 120 | 10 cm Gravel | 49 | 2 | |
| | Gravel | 37.0 | 45.0 | 80 | 5 cm Gravel | 24 | 2 | |
| Lunsar - Makeni | Paved | 0 | 10.0 | 1200 | Single Overlay | 240 | 2 | |

| RECOMMENDED PRIORITY LIST FOR YEAR 3 | | | | | | | | |
|--------------------------------------|-------|-----------|---------|----------------|--------------------|--------------------|-----------|--------------------------|
| ROAD NAME | TYPE | FROM (km) | TO (km) | TRAFFIC VOLUME | IMPROVEMENT POLICY | IMP. COST (\$1000) | NEED YEAR | OTHER YR. TO IMPROVE RD. |
| Lungi - Port Loko | Paved | 0 | 6.4 | 250 | Double Overlay | 230 | 3 | |
| Masiaka - P/Loko | Paved | 28.0 | 37.0 | 450 | Double Overlay | 360 | 3 | |
| Targrin - Lungi | Paved | 9.6 | 17.8 | 700 | Double Overlay | 295 | 3 | |
| Wellington - W/loo | Paved | 2.2 | 16.2 | 2312 | Double Overlay | 324 | 4 | |
| | Paved | 16.2 | 26.2 | 1540 | Double Overlay | 360 | 3 | |

| RECOMMENDED PRIORITY LIST FOR YEAR 5 | | | | | | | | |
|--------------------------------------|-------|-----------|---------|----------------|--------------------|--------------------|-----------|--------------------------|
| ROAD NAME | TYPE | FROM (km) | TO (km) | TRAFFIC VOLUME | IMPROVEMENT POLICY | IMP. COST (\$1000) | NEED YEAR | OTHER YR. TO IMPROVE RD. |
| Hill St. - Hastings | Paved | 0 | 7.5 | 240 | Single Overlay | 180 | 4 | |
| Masiaka - P/Loko | Paved | 0 | 10.0 | 800 | Double Overlay | 360 | 4 | |
| | Paved | 19.3 | 28.0 | 700 | Single Overlay | 208 | 5 | |
| F/town - Penin. Rd. | Paved | 37.0 | 45.0 | 450 | Single Overlay | 192 | 5 | |
| | Paved | 13.5 | 22.2 | 370 | Single Overlay | 268 | 4 | |
| | Paved | 22.2 | 30.2 | 370 | Single Overlay | 192 | 5 | |

* 2 (10) - This means road will be improved again in the second year with 10 cm. of gravel material.

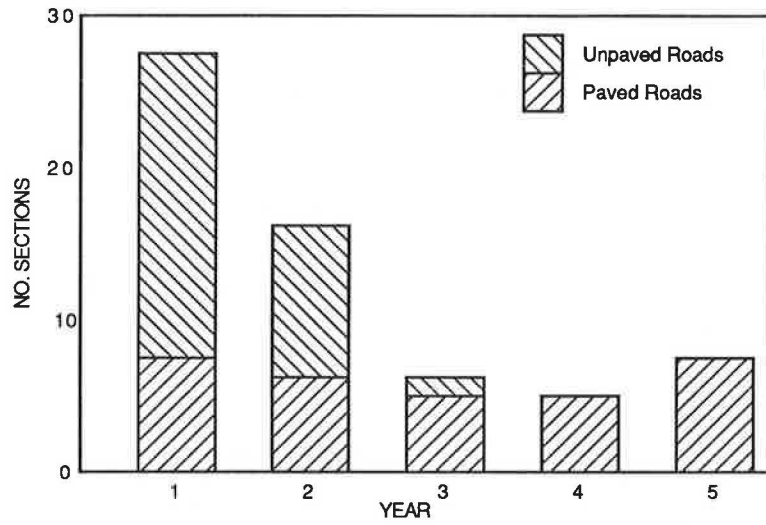


FIGURE 7 Distribution of priority list for a fixed annual budget of \$3.25 million.

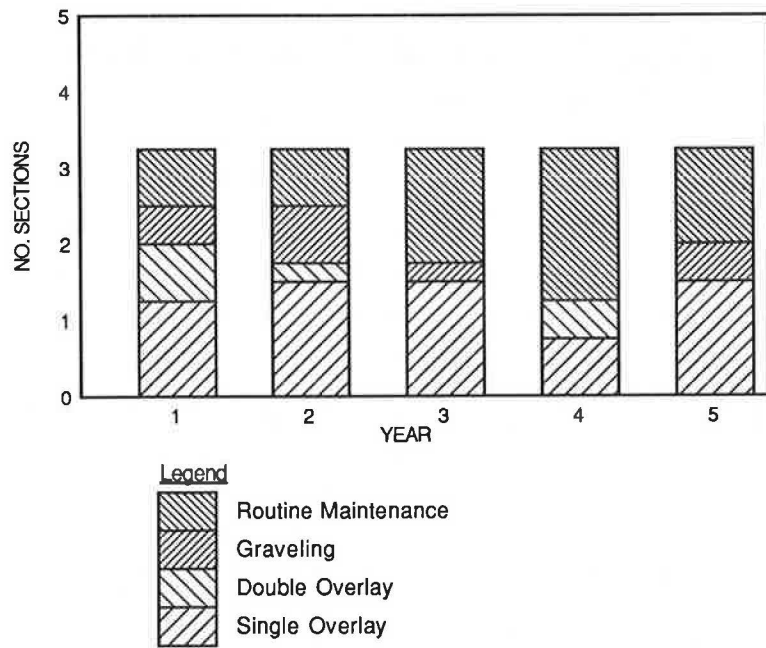


FIGURE 8 A breakdown of improvement costs on the priority list by paved and unpaved roads.

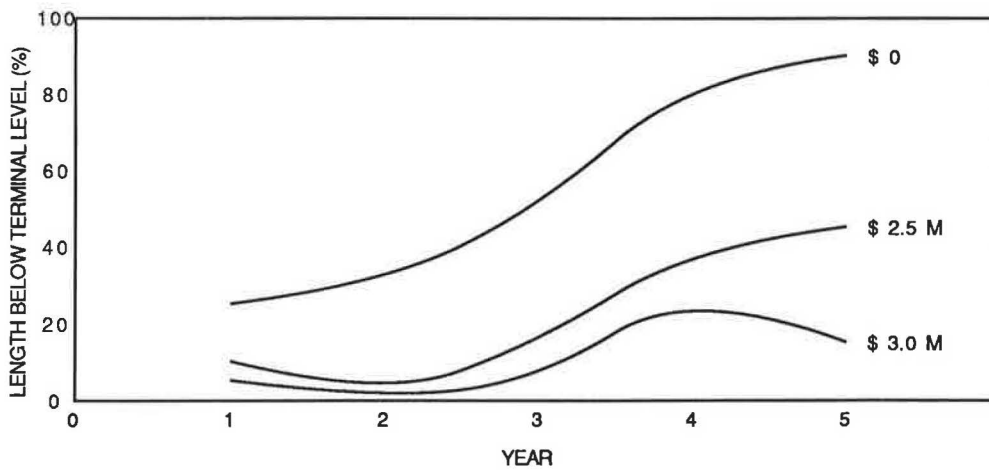
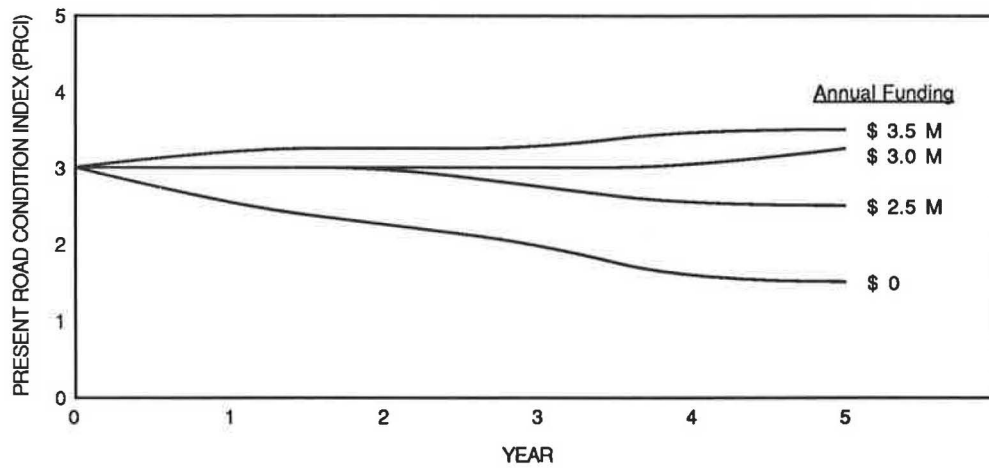


FIGURE 9 The effects of funding decisions on the average condition of the paved road sector.

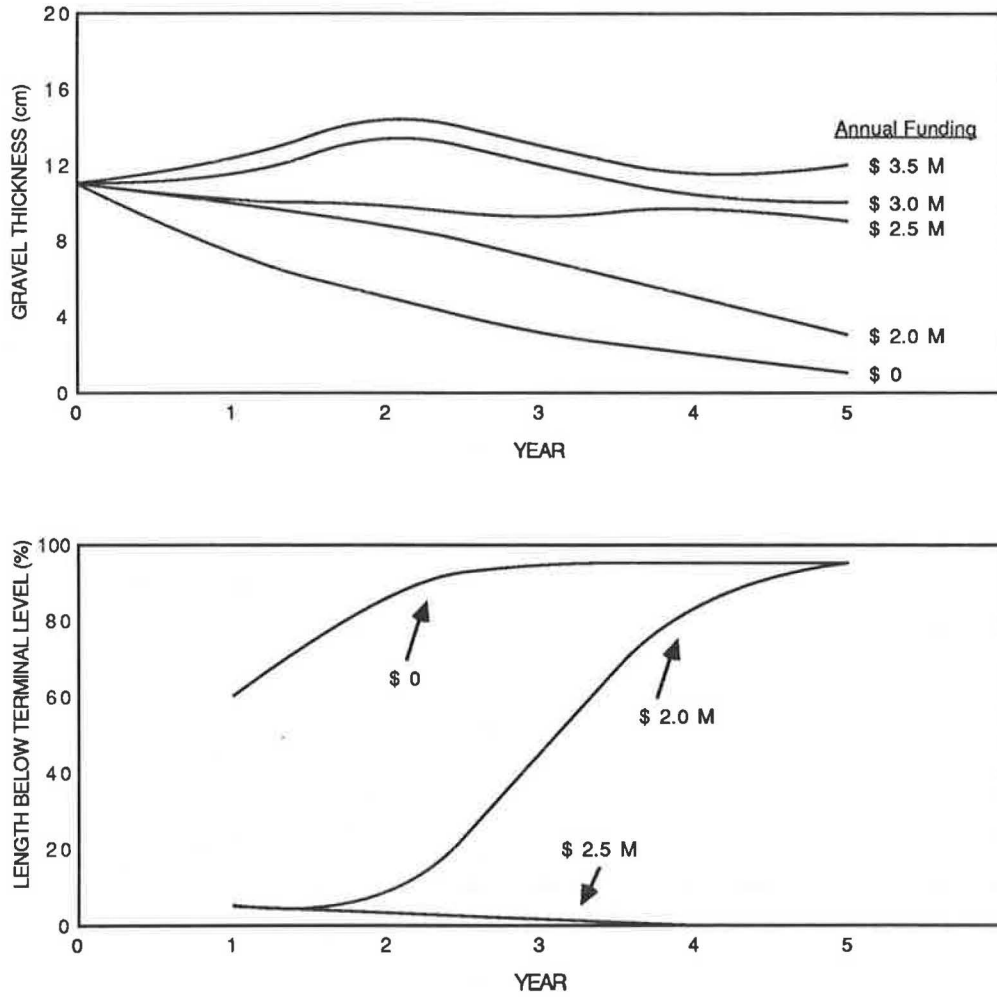


FIGURE 10 The effects of funding decisions on the average condition of the unpaved road sector.

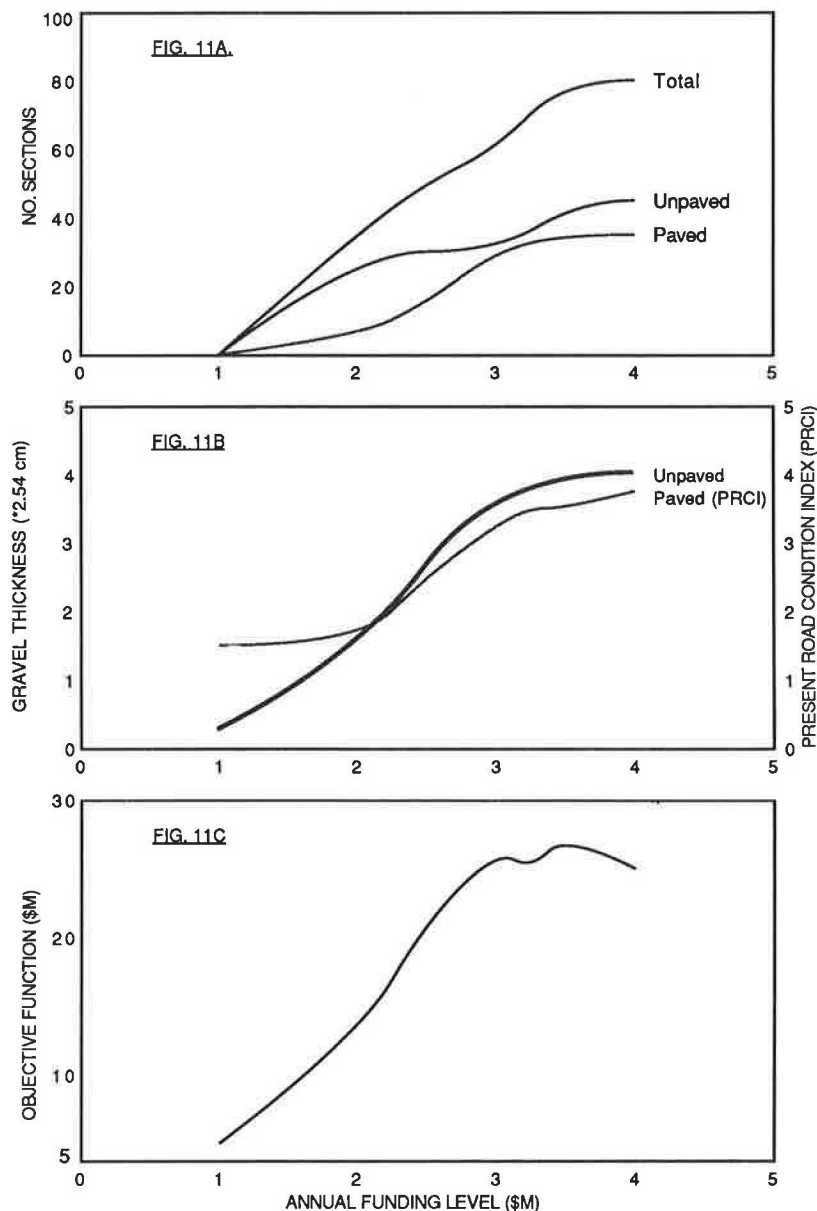


FIGURE 11 The effects of funding decisions on the average condition of the sample road network.

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