Evaluating Alternative Maintenance Strategies for Low-Volume Roads in Sub-Saharan Africa

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Recent applications of the World Bank's Highway Design and Maintenance (HDM) model in sub-Saharan Africa indicate that periodic maintenance is generally justified by vehicle operating cost savings only on paved roads with traffic levels of more than 100 vehicles per day (vpd) and on unpaved roads with traffic levels of more than 50 vehicles per day. If traffic levels are below 50 vpd on paved roads and 20 vpd on unpaved roads, the HDM indicates that periodic maintenance should be postponed indefinitely. Road rehabilitation in potentially productive areas often appears economically justified at lower traffic volumes, based on the increase in agricultural production that occurs when road access is provided. These benefits may be lost if a rehabilitated road is allowed to deteriorate because of lack of maintenance. The potential loss of agricultural production is not considered in the HDM evaluation of an optimal road maintenance strategy. The relationship between road condition and agricultural productivity to develop an appropriate maintenance strategy for low-volume roads in sub-Saharan Africa is examined in this paper. Timely periodic maintenance is generally justified if the initial road construction investment was justified. If the expected increases in agricultural production or the related generated traffic is slow to materialize, the preferred economic strategy would be to defer periodic maintenance for 2 to 4 years. It is critical that roads be maintained routinely to preserve road access, which is the key to the effects of road investments on development.

The countries of sub-Saharan Africa share several characteristics that lead to low traffic volumes on most of their rural roads. Much of sub-Saharan Africa is still sparsely populated. This population is largely engaged in subsistence agriculture and often employs shifting cultivation, combined with or complemented by transhumant or nomadic herding. The modern transport needs associated with these traditional patterns of economic activity are minimal.

The region is characterized by extremes of temperature and rainfall, which result in wide variations in vegetative cover and soil quality. Generally speaking, soils that are suitable for road building have relatively low agricultural potential, whereas soils with high agricultural potential are not well adapted for road construction and maintenance. The variations in climate also affect the choice of appropriate road maintenance strategies because, at low traffic volumes, climate is much more important than traffic in determining the rate of road deterioration.

The traditional approach to development in sub-Saharan Africa has been to encourage the rural population to produce cash crops for export to generate cash income that can then be exchanged for manufactured goods. Extensive road networks have been built, at considerable cost, in pursuit of this objective. In many cases, these road building programs have been associated with complementary investments to promote crop production or with rural development projects to promote rural welfare. However, growth in agricultural production has not kept pace with the growth of the population, which has resulted in declining levels of economic activity and low traffic volumes on much of the present road network.

Sub-Saharan African countries today are faced with critical decisions regarding the use of their scarce public resources. In the past, many countries have invested heavily in roads without allocating the necessary funds in their recurrent budgets to maintain these assets. Consequently, the benefits expected from these investments have not been fully realized. Roads that have been allowed to deteriorate due to lack of maintenance now require expensive rehabilitation or even complete reconstruction. Yet it is difficult to justify maintenance expenditures when traffic volumes remain low.

The World Bank called attention to the road maintenance problem in 1980 and has since been giving continuous attention to the development of analytic tools for planning and programming maintenance expenditures in the most cost-effective manner (*1, 2*). More recently, it has focused attention on the resource allocation problems raised by road deterioration in the absence of adequate maintenance (*3*). Although the problem is worldwide, the Bank has been giving particular attention to sub-Saharan Africa, where development efforts have been least successful and where resource constraints are most severe.

Recent applications of the Bank's analytic tools, the Highway Design and Maintenance (HDM) model and its companion Expenditure Budgeting Model, have been made using the road networks of several sub-Saharan African countries. This work has shown that periodic maintenance is generally justified by user cost savings at traffic levels approaching 100 vehicles per day (vpd) for paved roads and 50 vpd for earth roads. There is a gray area in which periodic maintenance may or may not be justified, depending on the unit costs of the maintenance activity and on the vehicle mix using the road. This gray area lies roughly between 50 and 100 vpd for paved roads and between 20 and 50 vpd for gravel roads. The HDM analysis indicates that below these traffic levels periodic maintenance should be postponed indefinitely.

At the same time, however, road rehabilitation and construction studies often show that larger infrastructure investments would be viable at lower initial traffic levels. The reason for this apparent inconsistency is that construction and rehabilitation studies take into account the effect of road improvements in generating—or regenerating—economic activity in the surrounding area, apart from the normal growth of traffic that is

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considered in maintenance analysis. The purpose of this paper is to examine the relationship between road condition and agricultural productivity in greater detail to determine the most appropriate maintenance strategy for low-volume roads.

METHODOLOGICAL APPROACHES

The classic methodology for estimating the benefits of road investment is based on user cost savings (*4*). This methodology underlies the HDM model, which estimates user costs as a function of changing road conditions for a given vehicle mix, traffic growth pattern, and time period. The application of different maintenance and improvement strategies, with their associated cost streams, produces different road conditions over time, with associated user cost streams. The HDM model defines the optimal strategy as the one that has the lowest total net present value. The Expenditure Budgeting Model will select the next best program of maintenance activity under budget constraints, when sufficient funds are not available to implement the optimal strategy.

It has long been recognized that user cost savings reflect only a rough measurement of the benefits accruing to society from road investments (*5*). In particular, the user cost approach does not adequately describe what happens when road access is provided in rural areas. Rural road construction is not merely an incremental change in an existing situation. Roads fundamentally transform the rural way of life by providing opportunities for contact and communication with a wider world. In particular, rural roads provide access to markets, which enables specialization of production and exchange between producers and consumers. Road access is a prerequisite for development programs that are based on the production of cash crops, for which imported inputs and information are needed, as well as markets in which surplus production can be sold. In short, rural roads facilitate the transformation of the rural economy from a static system based on subsistence to a dynamic system based on trade with the outside world.

A methodology to justify rural road investments in terms of the value added in agriculture as a result of the expected change in production has been developed by Carnemark et al. (*6*). This approach is commonly used in evaluating rural road investments that are part of a rural development package. Beenhakker has shown that the value-added approach is conceptually equivalent to the user cost savings approach (*7*). If rural markets were perfect and if all transactions were reflected in transport activity, the benefits of rural road investments would indeed correspond to measurable changes in traffic.

The value-added approach assumes that, by reducing transport costs, a rural road improvement will provide an adequate incentive for traders to purchase cash crops at a price that makes it rewarding for the farmer to produce them. It further assumes that these reduced transport costs will be in effect over the life of the project—in other words, that the road will be maintained so that its condition will not deteriorate. Maintenance costs are included in calculating the costs of the improvement. Consequently, if the initial investment is justified, subsequent maintenance should also be justified.

THE PROBLEM

A maintenance planner could be faced with a problem 5 to 10 years after the initial investment was made, that traffic on the road does not appear to justify the planned investment in periodic maintenance. Should the road be abandoned? Should it be allowed to deteriorate to the point where rehabilitation will become necessary? Or should it be maintained, regardless of present traffic levels, in order to preserve the benefits of the rural development program?

The answers to these questions are not obvious. A number of other questions need to be answered before a truly optimal maintenance policy can be determined.

Has the Rural Development Program Failed?

It is possible that the failure of traffic to materialize reflects a genuine failure of the development process. This may be due to physical constraints that were not adequately taken into account in planning investments, such as limited area of suitable soils or inadequate water supply. It may be due to socioeconomic factors such as inappropriate land tenure systems, labor force constraints, or lack of marketing and credit facilities. It may be due to incorrect sector policies on matters such as pricing and taxation, or to the promotion of unsuitable technical packages. Finally, it may be due to unfavorable changes in international commodity markets. All of these are factors over which the maintenance planner has no control. There is no reason to expect that additional investment in road maintenance will reverse the situation, and periodic maintenance in this case is not justified.

Is the Lag Time Longer Than Expected?

Rural development programs are frequently optimistic in forecasting the speed with which new technologies will be adopted and new production will take place. The expected change process often does take place but at a somewhat slower rate than expected. This delay reduces the rate of return on the original investment package, but this is not the concern of the maintenance planner. From his point of view, the original investment is a sunken cost. What he must be concerned with is the return on a periodic maintenance investment that will keep the road in service for a longer period. Because periodic maintenance represents only a fraction of the cost of the original investment, periodic maintenance is likely to be justified in this case.

Is the Development Process Taking a Different Form?

Although rural development programs often fail to achieve their intended objectives, particularly if those objectives are defined in terms of the increased production of cash crops, they may well achieve other results that could be seen as contributing to rural welfare. Many of these results depend directly on road access, even though they do not generate great amounts of traffic. Farmers may apply extension advice and inputs such as fertilizer and pesticides to the production of food crops for on-farm consumption and local exchange. Women may be able to diversify family diets through small-scale production of vegetables, fruits, and poultry products. Health and education services may reach out to rural areas, and human factors of production may improve. A wider range of commercial goods may appear in local markets, thereby providing incentives for

more productive use of leisure time in cash-generating activities. Underutilized labor may respond to a wider range of employment opportunities. A growing network of social relations may begin to link the rural community into regional and national systems.

In this situation, a real cost is associated with road deterioration, especially when a road reaches the point where it is no longer trafficable. Rising road user costs due to deterioration create negative incentives for road use to service providers, traders, and transporters from outside the area, as well as to those rural residents who can afford to use vehicles. At some point, the costs will become too great, and the critical actors in the rural development process will simply cease to use the roads. In an extreme case, the countryside will revert to a subsistence economy, but with this difference—rural residents, the "beneficiaries" of the original investment, will have become deeply disillusioned about development and will be more reluctant to take the risks associated with change and growth in the future.

A MODEL FOR EVALUATING MAINTENANCE INVESTMENT

A proposed model for evaluating alternative strategies for the maintenance of improved low-volume rural roads in potentially productive agricultural areas is described in the following paragraphs. The model is based on experience in sub-Saharan Africa, where road deterioration followed by reversion to a subsistence economy can frequently be observed. The principles of the model, however, can be applied to any developing area. In cases where the development process is less problematic than it is in sub-Saharan Africa, the priority of periodic maintenance should be more readily demonstrated.

Consider the case of an unpaved road, the initial construction cost of which is C, and the expected lifetime of which is t years with annual routine maintenance costs of r(C) and periodic maintenance costs every n years of p(C). It is assumed at the time of road construction that agricultural production will increase by x percent per year for y years as a result of the road. For the sake of simplicity, it can be assumed that no complementary investments are needed to generate this change in production.

The benefit of the investment is the value added due to the increase in agricultural productivity, or the difference between the farmgate value of production and the cost of inputs (including farm labor) multiplied by the increment of production. Again for the sake of simplicity, let us assume that the crop mix, the farmgate price of crops, and the cost of inputs do not change over the analysis period. (This assumption is commonly made to ease the computation of expected benefits, but it is not essential to the analysis. What matters is what will happen to the net value added in agriculture, taking into account all of these factors.) Total benefits are represented by the discounted stream of incremental production benefits and total costs by the discounted stream of construction and maintenance costs.

To illustrate this model, let us assume that the lifetime of the road is 25 years, annual routine maintenance costs are 5 percent of construction costs, and periodic maintenance costs are 20 percent of construction costs every 8 years. Let us further assume that the value of agricultural production (V) will increase by 5 percent per year for 10 years as a result of road construction. (This factor could also represent the share of the growth in value added that is attributable to roads that are part of integrated rural development projects.)

In this case, the present value of benefits (discounted at 12 percent) is 2.555(V) and the present value of costs (discounted at 12 percent) is 1.317(C). The investment is justified when the net present value (benefits minus costs) is greater than zero or, in other words, the rate of return is greater than 12 percent. The limiting case is given by 2.555(V) = 1.317(C), or C = 1.94(V). In other words, under the assumptions outlined above, the investment is justified when construction costs are approximately twice the value added in agriculture prior to construction. The rate of return on the case where C = 2V is 11.6 percent.

Let us now consider what will happen if the roads are not periodically maintained. If routine road maintenance is regularly performed, unit road user costs will remain approximately constant for the first 8 years. After that, the road will begin to deteriorate and user costs will gradually increase. Eventually, the condition of the road will reach a point where user costs will become a major deterrent to traffic and the road will be, for all practical purposes, abandoned. If routine maintenance is not regularly performed, the road will deteriorate much more rapidly and will eventually become impassable and therefore will require complete rehabilitation. However, for this example, let us assume that routine maintenance continues and that the road gradually deteriorates until the surface is completely lost (Figure 1).

A critical assumption concerns the rate of growth of user costs with deferred maintenance. Let us assume that after the first 8 years, user costs will increase by about 10 percent per year in the absence of timely periodic maintenance. If the benefits of value added in agriculture decrease in proportion to increased user costs, this would mean a loss of 9 percent in the benefits expected in year 9 and of about 18 percent in the benefits expected in year 10. In the following years, expected agricultural benefits will not increase, and losses due to road deterioration will continue to mount. If no periodic maintenance is done, these losses could amount to 80 percent of incremental annual production by the end of the analysis period.

In actual fact, however, user costs do not increase indefinitely. At some point, the surface of the road will become completely worn away but the structure, which is preserved through routine maintenance, will still remain intact. Let us assume that this occurs after about 6 years of deterioration, when the road reaches its worst condition consistent with continued routine maintenance. At this point, losses would amount to about 40 percent of potential benefits. Under these assumptions, with an initial investment the rate of return of which is 11.6 percent, the rate of return for a timely investment in periodic maintenance, calculated over a 14-yr period, treating previous investments as sunk costs, and assuming that routine maintenance is regularly provided, is 12.4 percent.

SENSITIVITY TO ASSUMPTIONS

Before using this model to explore the effects of deferred maintenance, let us examine the effects of possible changes in some of the basic assumptions. For example, if the pattern of increasing agricultural production originally attributed to the road had been expected to extend over 15 years, the periodic maintenance investment would have a rate of return of 27.3 percent (Figure 2). In this case, failure to maintain the road in year 8 would cause agricultural production to level off at about

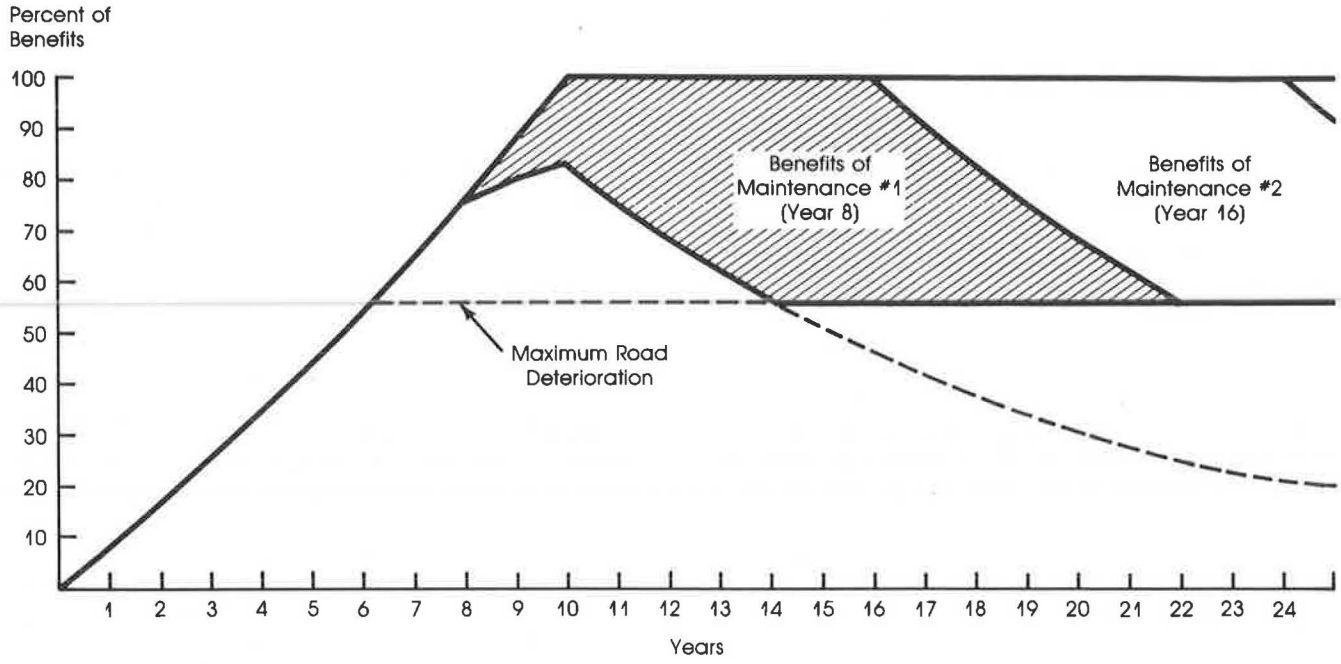

FIGURE 1 **Benefits of timely periodic maintenance; benefit growth = 10 years and maintenance interval = 8 years.**

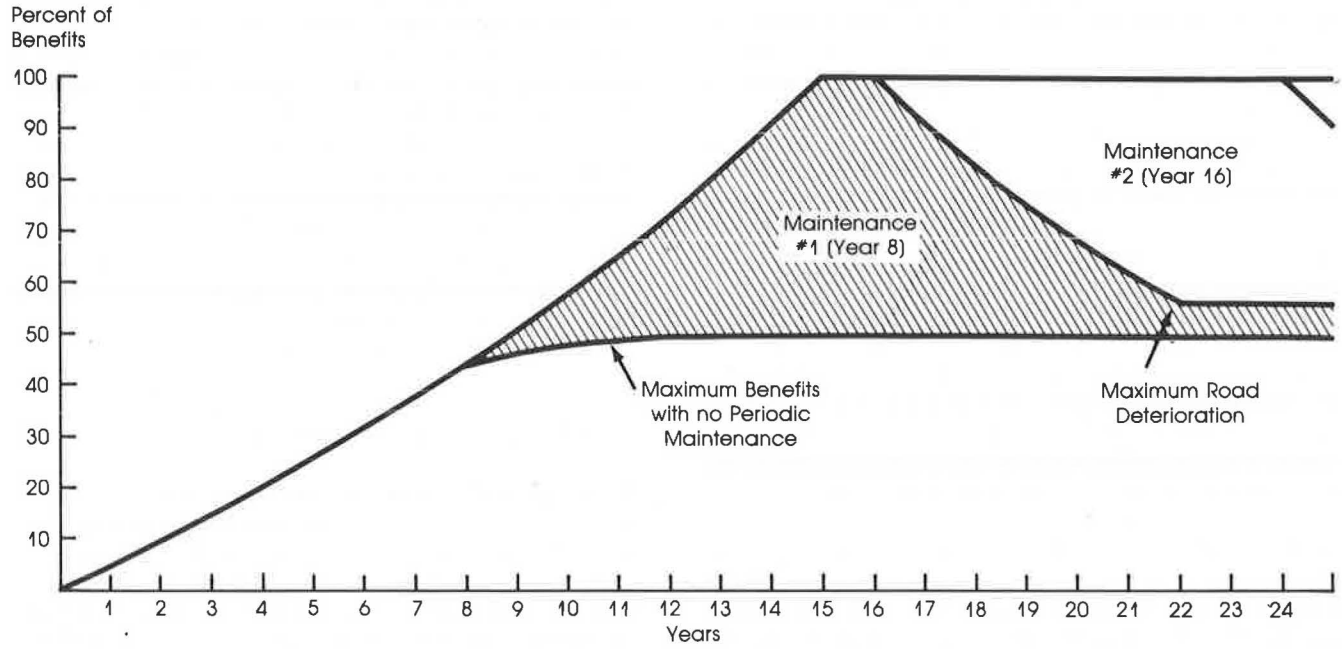

FIGURE 2 **Benefits of timely periodic maintenance; benefit growth = 15 years and maintenance interval = 8 years.**

50 percent of the maximum potential production. If periodic maintenance is done in year 8, agricultural production will reach its expected maximum in year 15, as planned. Failure to execute periodic maintenance a second time in year 16 would cause this maximum production to decline, but it would level off at the rate corresponding to the maximum road deterioration, which in this case would be higher than the maximum benefits gained with no periodic maintenance.

If periodic maintenance is needed at more frequent intervals, a smaller proportion of the benefits depends on each maintenance expenditure and the expenditure becomes more difficult to justify. For example, if periodic maintenance needs to be performed after 5 years, and benefits are expected to grow over 10 years, the rate of return on the periodic maintenance investment alone would be -5.9 percent (Figure 3). In this case, benefits in the absence of timely road maintenance would reach a level just slightly higher than those corresponding to the maximum road deterioration. If benefits were expected to extend over 15 years, a failure to perform periodic maintenance in year 5 would cause the benefits to plateau at less than 40 percent of their potential (Figure 4). Periodic maintenance would be needed again in year 10 and if it were not performed, the benefits would peak at about 60 percent of the potential and then decline to the level corresponding to maximum road deterioration.

The model is also somewhat sensitive to the proportion of the original construction costs required for periodic maintenance, which is here assumed to be 20 percent. If, in our example, periodic maintenance costs 25 percent of construction costs, the rate of return on an 8-yr cycle with a 10-yr benefit growth period would fall to 8.3 percent, and the expenditure would no longer be justified. With benefits growing over 15 years, the rate of return would be 23.1 percent instead of 27.3 percent. If periodic maintenance would be necessary after 5 years, the rate of return would be -9.2 percent with a 10-yr benefit period and 5.6 percent with a 15-yr period.

Finally, our example considers an original investment, the rate of return of which is close to 12 percent, which is generally accepted as the minimum rate needed to justify an investment package. An initial investment with a higher rate of return would clearly justify a greater expenditure on periodic maintenance, all other things being equal.

EFFECTS OF ALTERNATIVE MAINTENANCE STRATEGIES

Consider the alternative strategy of deferring periodic maintenance (Figures 5 and 6). One consequence of deferral is a higher cost when the maintenance does take place, which will be calculated by spreading the assumed cost over the time period considered. Thus, if periodic maintenance is required every 8 years and costs 20 percent of construction costs, it is assumed that each year of deferral would add 2.5 percent to the cost factor. If periodic maintenance has to be done every 5 years and costs 20 percent of construction costs, each year of deferral would add 4 percent to the cost factor.

A major consequence of deferral is that benefits of the original investment are reduced for the years when periodic maintenance should have taken place but did not. These reductions represent the losses that would have been avoided if periodic maintenance had been performed in a timely manner. We will assume that deferred periodic maintenance restores the

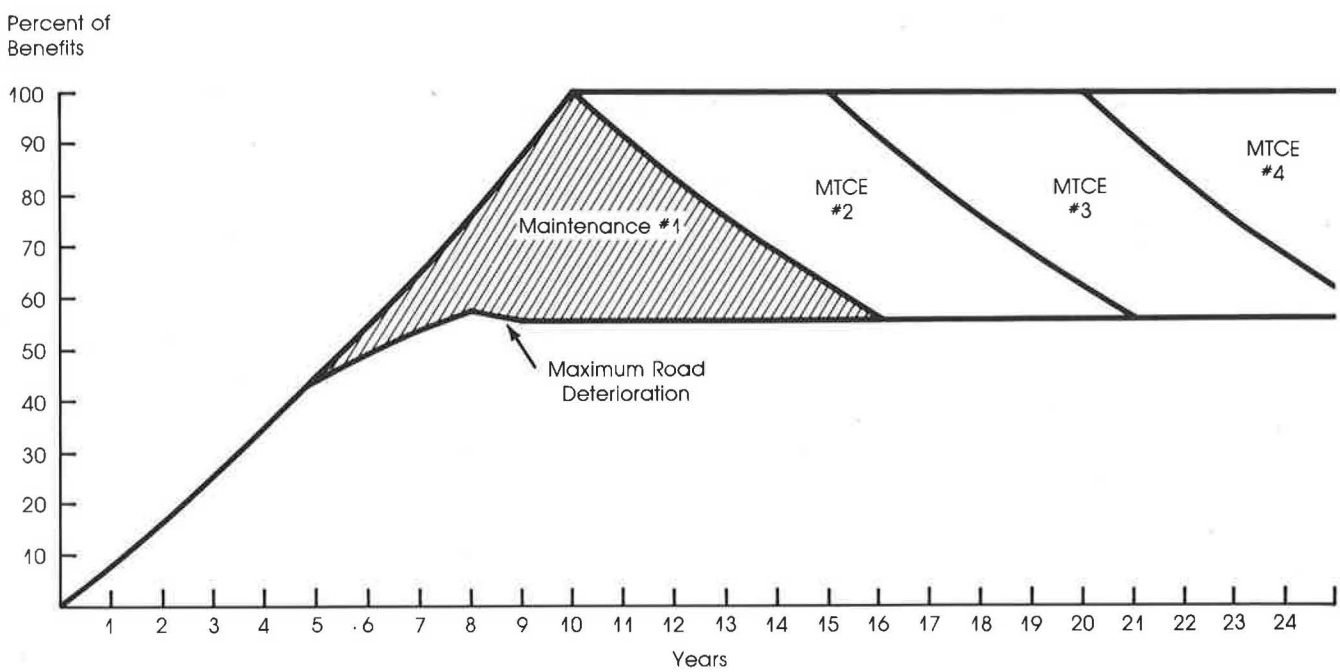

FIGURE 3 Benefits of timely periodic maintenance; benefit growth = 10 years and maintenance interval = 5 years.

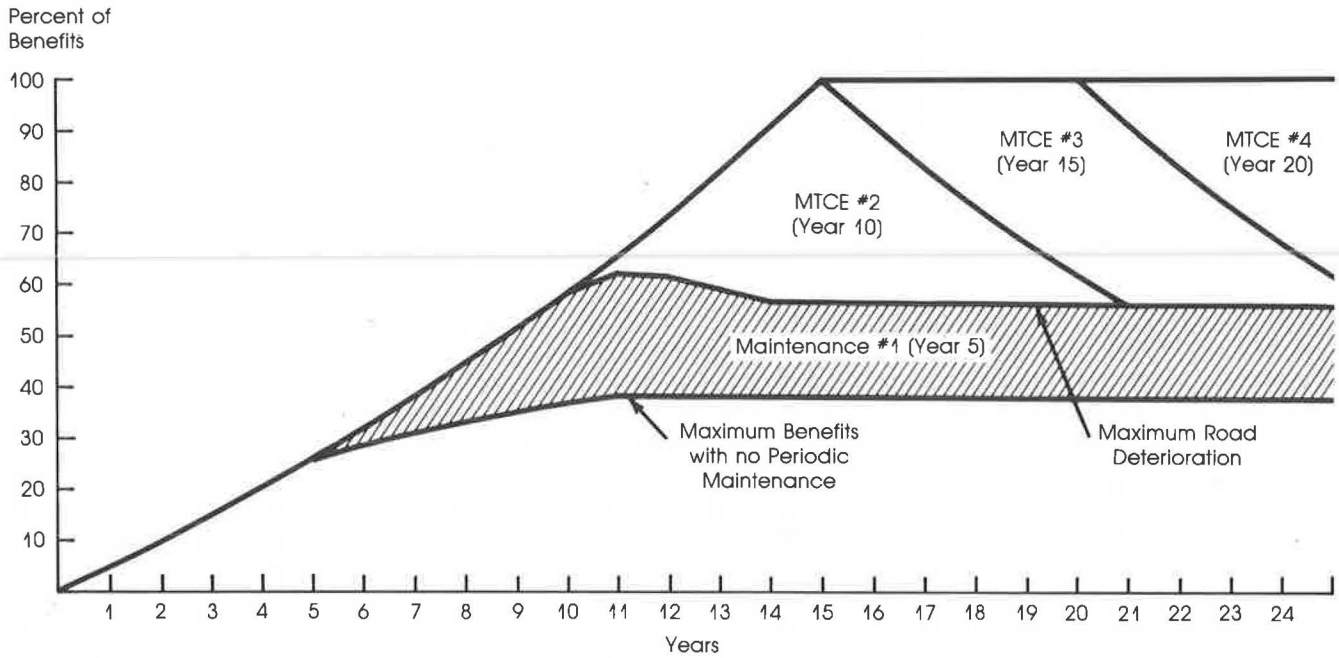

FIGURE 4 Benefits of timely periodic maintenance; benefit growth = 15 years and maintenance interval = 5 years.

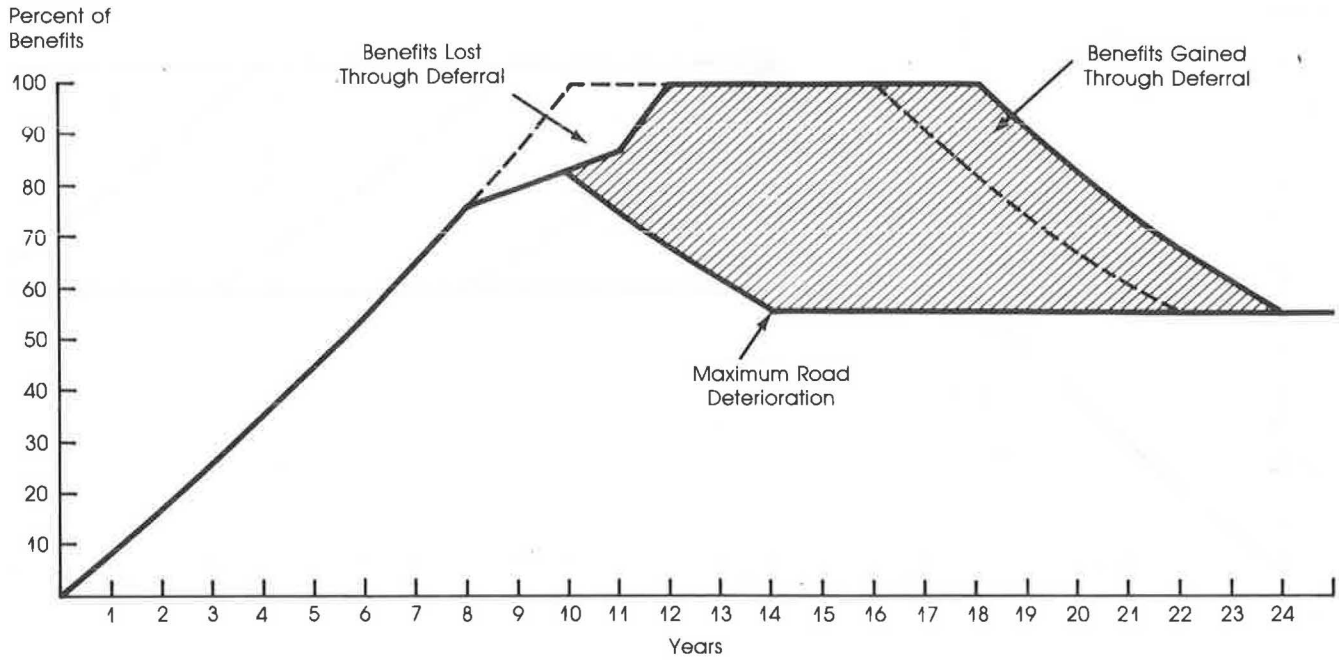

FIGURE 5 Benefits of deferred maintenance (10 years); benefit growth = 10 years and maintenance interval = 8 years.

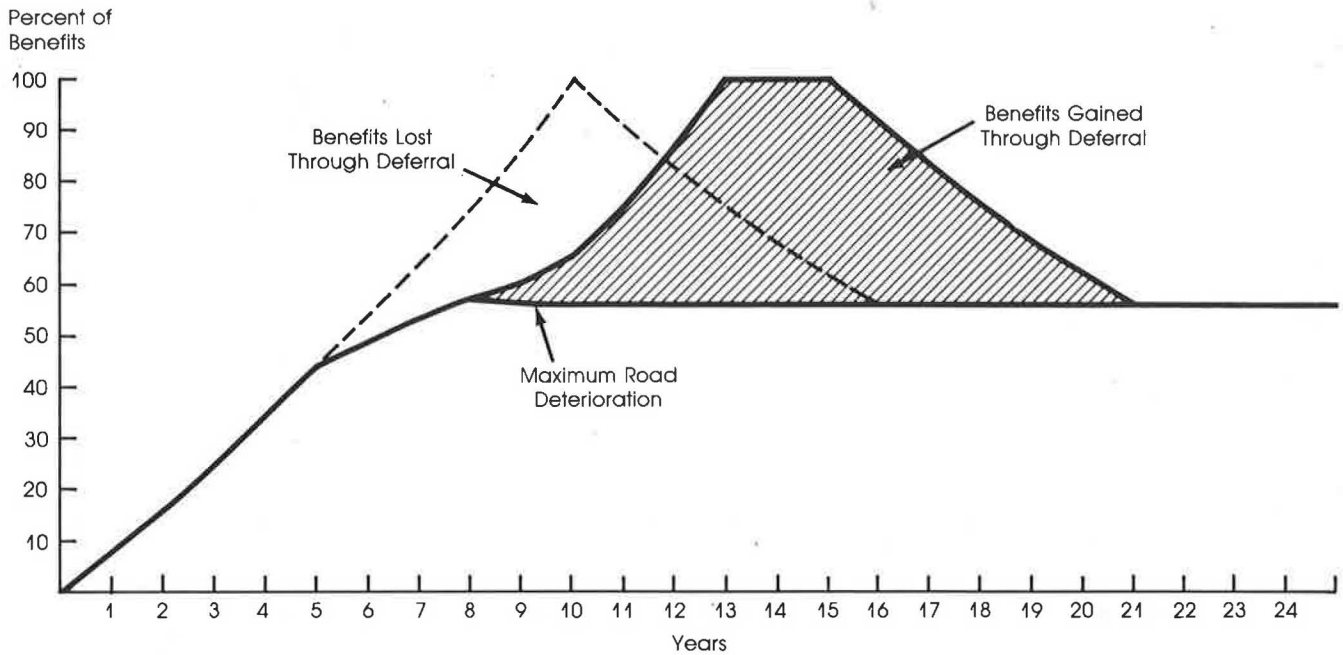

FIGURE 6 Benefits of deferred maintenance (8 years); benefit growth = 10 years and maintenance interval = 5 years.

road surface to its original good condition, and that routine maintenance retains this condition until periodic maintenance is due once again.

In the case of maintenance, which should, from a technical point of view, be done every 8 years, rates of return can be calculated for maintenance deferred to years 10, 12, 14, or 16 (Table 1). This comparison shows that deferred maintenance would give the highest rate of return between year 12 and year 14. To determine the optimal year for deferred maintenance, the net present values of these alternative strategies are compared for the year of timely periodic maintenance, which is the year in which the decision has to be made. This analysis suggests that year 12 is the optimal year in both cases (Figures 7 and 8).

A similar analysis for the situation in which periodic maintenance is needed every 5 years is shown in Table 2. In this case, deferring periodic maintenance to years 8, 10, 12, or 15 was considered. As shown in Table 2, periodic maintenance is never justified in this case, but timely maintenance is the optimal strategy if benefits extend over 10 years, and deferring periodic maintenance to year 10 is the optimal strategy if benefits are expected to extend over 15 years.

TABLE 1 MAINTENANCE INTERVAL OF 8 YEARS

	NPV in Year 8	IRR (%)
Benefit growth over 10 years		
Timely maintenance (Year 8)	0.004	12.4
Deferred maintenance (Year 10)	0.020	16.3
Deferred maintenance (Year 12)	0.054	19.8
Deferred maintenance (Year 14)	0.039	16.9
Deferred maintenance (Year 16)	0.000	12.0
Benefit growth over 15 years		
Timely maintenance (Year 8)	0.235	27.3
Deferred maintenance (Year 10)	0.296	38.0
Deferred maintenance (Year 12)	0.306	47.1
Deferred maintenance (Year 14)	0.248	45.8
Deferred maintenance (Year 16)	0.180	39.5

TABLE 2 MAINTENANCE INTERVAL OF 5 YEARS

	NPV in Year 5	IRR (%)
Benefit growth over 10 years		
Timely maintenance (Year 5)	-0.124	-5.9
Deferred maintenance (Year 8)	-0.136	-8.8
Deferred maintenance (Year 10)	-0.147	-12.4
Deferred maintenance (Year 12)	-0.156	-20.3
Deferred maintenance (Year 15)	-0.163	-24.1
Benefit growth over 15 years		
Timely maintenance (Year 5)	-0.047	8.2
Deferred maintenance (Year 8)	-0.063	4.8
Deferred maintenance (Year 10)	-0.050	6.0
Deferred maintenance (Year 12)	-0.053	4.8
Deferred maintenance (Year 15)	-0.068	0.8

CONCLUSIONS

The conditions under which periodic maintenance investment in unpaved rural roads can be justified by losses avoided in agriculture alone are relatively restrictive. In the case of a barely feasible initial investment, the benefits of which extend over 10 years, timely periodic maintenance is likely to be justified only if

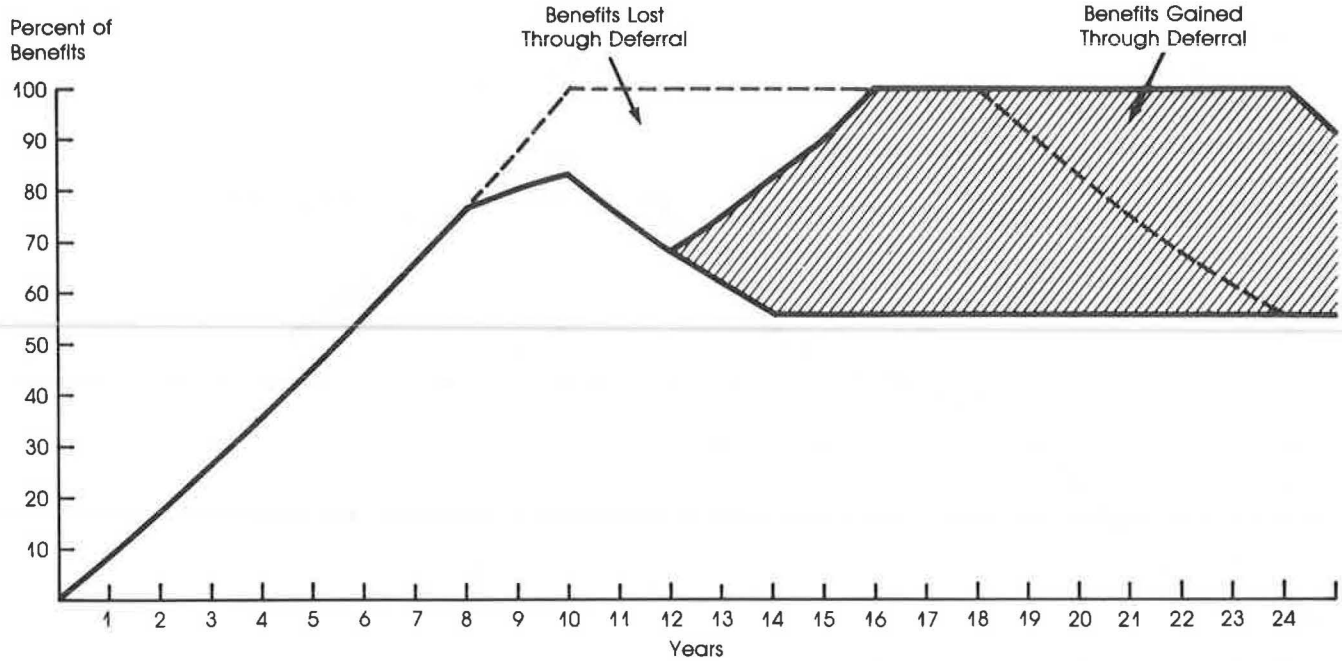

FIGURE 7 Benefits of deferred maintenance (12 years); benefit growth = 10 years and maintenance interval = 8 years.

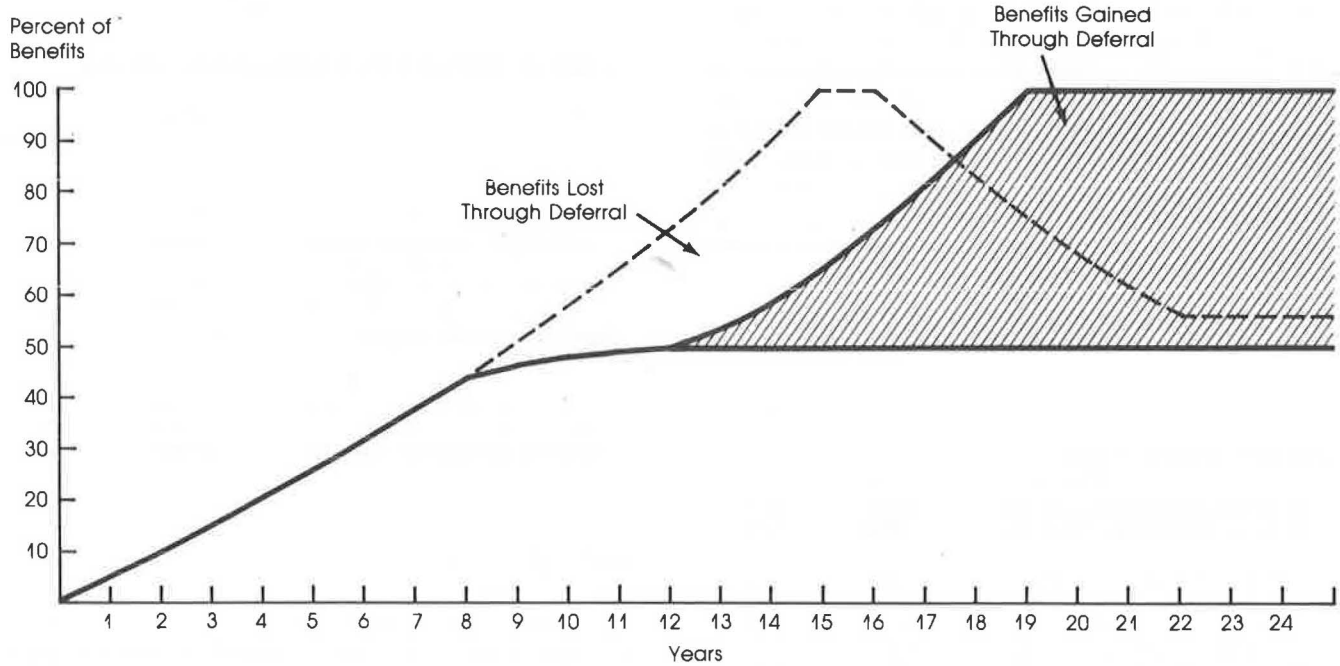

FIGURE 8 Benefits of deferred maintenance (12 years); benefit growth = 15 years and maintenance interval = 8 years.

maintenance costs are less than 20 percent of construction costs and the maintenance interval is 8 years or more. Furthermore, even in this case, a more efficient use of resources will be achieved by deferring maintenance for 2 to 4 years. Should benefit growth extend over a longer period, timely maintenance would become more feasible, but the economically optimal year of maintenance would still be 2 to 4 years later than the year that would be selected according to technical criteria.

Roads that require periodic maintenance at frequent, 5-yr intervals are difficult to justify with agricultural benefits. Unless the costs of such maintenance are considerably less in relation to construction costs than we have assumed here (or construction costs are less in relation to agricultural value added), it might be worthwhile to consider an alternative design standard with higher initial costs that can support traffic for a longer time before periodic maintenance would be needed.

Two caveats should be noted here. The first is a reminder that the model assumes that routine maintenance is regularly performed, even in the absence of periodic maintenance, thereby ensuring that the road does not suffer serious structural deterioration. Expenditures on routine maintenance are almost always justified, even at extremely low traffic levels. However, it is often the case that routine maintenance is not done or is not correctly done. In this situation, the road will deteriorate faster and the benefits and costs of periodic maintenance will be higher than shown here.

A second caveat is that the benefits here calculated in terms of losses avoided in agriculture are at least partly reflected in agricultural traffic. Therefore, they cannot simply be added to the user cost savings for existing and projected traffic. Theoretically, user cost savings for non-agricultural traffic could be counted in addition to losses avoided in agriculture. However, in practice it is often difficult to distinguish between agricultural and non-agricultural traffic in rural areas. Therefore, the most prudent approach would be to analyze alternative maintenance strategies either in terms of user cost savings (for traffic volumes above 50 vpd for paved roads or 20 vpd for earth roads) or of value added in agriculture (for roads with lower traffic volumes).

OTHER CONSIDERATIONS

Non-economic considerations often play a major role in government decision-making on the maintenance of low-volume roads in areas of strategic or political significance. A minimal priority network is needed in each country to ensure social cohesion and to enable governments to fulfill their obligations in times of crisis, such as war or famine. In such cases, the appropriate maintenance strategy would be the least costly alternative to ensure minimum access. In countries where traffic levels are extremely low, it may be more sensible for governments to seek alternative solutions to meet basic access needs instead of maintaining an extensive road network.

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