A WORLD BANK POLICY STUDY

June 1988

Road Deterioration in Developing Countries

Causes and Remedies

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The World Bank
Washington, D.C.

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Foreword

The failure to maintain roads is tantamount to an act of disinvestment, for it implies the sacrifice of past investments in roads. Over the past two decades an estimated $45 billion worth of road infrastructure has been lost owing to inadequate maintenance in the eighty-five developing countries reviewed in this policy study. This loss could have been averted with preventive maintenance costing less than $12 billion.

The loss of physical infrastructure is only part of the picture. Bad roads seldom deter users or curb the volume of traffic. Instead, they raise the cost of road transport—the dominant mode of transport for both people and freight in most countries. A dollar reduction in road maintenance expenditures can increase the cost of vehicle operation by two to three dollars. Insufficient spending for maintenance thus exacts hidden costs several times the cost of maintaining and restoring roads. Road users bear the brunt of these additional costs, which dwarf the savings to a road agency from deferring or neglecting maintenance.

Much of the problem of road maintenance is rooted in its economic and institutional aspects. Inadequate incentives and weak accountability derive from the characteristic separation of responsibilities and control between the providers and users of roads. Unlike most other types of infrastructure, roads are neither built nor maintained by those who use them to market output or services.

Road deterioration is not confined to developing countries. Nor is it a new concern for the World Bank, which published *The Road Maintenance Problem and International Assistance* in 1981 to draw attention to the matter. What is new, however, is the scale to which road deterioration has progressed in so many developing countries. In this study we have attempted to estimate the physical and financial magnitude of the deterioration and to identify remedial measures appropriate to the circumstances of different countries. We have also tried to determine the principal causes of road deterioration and the reasons the problem has become so widespread. Economic adversity is part of the explanation, past mistakes in investment choices are another, but a large part of the problem has to be attributed to institutional failure in the countries themselves.

The quantification of losses underscores the importance of the problem, and the search for causes points the way to needed change and adjustment. Fortunately, the magnitude of the task is lessened by advances in engineering knowledge and experience that permit greater flexibility in the design of road maintenance strategies and a wider selection of solutions. This study describes some of the options and presents an institutional framework for implementing them in developing countries. It provides an estimate of the resources needed to remedy the situation and suggests ways to use these resources efficiently. The recommendations are addressed to the developing countries, the lending and donor agencies, and the development community at large, including the World Bank.

This report provides an early warning of a transportation crisis in developing countries that will occur if the escalating damage to roads is not contained. The portents of such a crisis are visible in the deteriorating road transport conditions in some developing countries. Without corrective action, many more developing countries may soon face a situation in which poor roads, and therefore inadequate road transport, become an insurmountable obstacle to economic recovery and growth.

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Glossary

Road Conditions

Good. Paved roads substantially free of defects and requiring only routine maintenance. Unpaved roads needing only routine grading and spot repairs.

Fair. Paved roads having significant defects and requiring resurfacing or strengthening. Unpaved roads needing reshaping or resurfacing (regraveling) and spot repair of drainage.

Poor. Paved roads with extensive defects and requiring immediate rehabilitation or reconstruction. Unpaved roads needing reconstruction and major drainage works.

Road Maintenance and Improvement Works

Routine maintenance. Local repair of roadway and pavement; grading of unpaved surfaces and shoulders; regular maintenance of road drainage, side slopes, verges, traffic control devices, and furniture; roadside cleaning, dust and vegetation control, snow or sand removal, and maintaining rest areas and safety appurtenances. Typical costs range from less than $300 a kilometer to more than $5,000 a kilometer.

Resurfacing. Regraveling an unpaved road or resurfacing a paved road (with a thin asphalt overlay, a surface treatment, or a seal coat) to preserve its structural integrity and ride quality. A paved road normally needs resurfacing at the transition from good to fair condition, provided the volume of traffic justifies retaining it in good condition. Resurfacing is sometimes called "periodic maintenance," even though all maintenance activities are periodic. Costs can vary from less than $8,000 a kilometer to more than $40,000 a kilometer.

Rehabilitation. Selective repair, strengthening, and shape correction of pavement or roadway (including minor drainage improvements) to restore structural strength and ride quality. The term "strengthening" is sometimes used to describe a specific category of pavement rehabilitation involving the application of overlays. Costs of rehabilitation can vary from less than $30,000 a kilometer for unpaved roads to more than $200,000 a kilometer for paved roads. The costs for paved roads, however, rise steeply as a pavement deteriorates from fair to poor condition.

Reconstruction. Renewing the road structure, generally using existing earthworks and road alignments, to remedy the consequences of prolonged neglect or where rehabilitation is no longer possible. Costs can vary considerably, ranging from about $45,000 a kilometer to more than $300,000 a kilometer.

Restoration. Major rehabilitation and reconstruction works considered together.

Betterment. Road improvements related to the width, alignment, curvature, or gradient of road (including associated resurfacing and rehabilitation works) to improve traffic speed, safety, or capacity. Betterment works are not considered maintenance activities except for ancillary road rehabilitation or resurfacing operations. Costs can vary considerably, depending on the geometric improvements.

New construction. Constructing a paved, gravel, or earth road on a new alignment; upgrading a gravel or earth road to paved standards; providing additional lane capacity; or constructing additional carriageways, frontage roads, grade-separated interchanges, or multilane divided highways. Costs of new construction can vary from less than $50,000 a kilometer for a gravel road to more than $1 million a kilometer for a four-lane access-controlled divided highway.

Acronyms and Initials

IDA	International Development Bank
IBRD	International Bank for Reconstruction and Development
GNP	gross national product
IRI	International Roughness Index
HDM	Highway Design and Maintenance Standards Study
HDM-III	Highway Design and Maintenance Standards Model
PRA	Public Roads Administration

Data Notes

"Dollars" are current U.S. dollars unless otherwise noted. "Billion" is 1,000 million. "Tons" are metric tons, equal to 1,000 kilograms, or 2,204.6 pounds. Numbers in tables may not add up to given totals because of rounding.

Summary

The developing countries have lost precious infrastructure worth billions of dollars through the deterioration of their roads. If they do not immediately begin to do much more to preserve their roads, they will lose billions more. Large road networks, built at great expense, have been undermaintained and more heavily used and abused than expected. If this neglect continues, the deterioration of roads will accelerate as old pavements crumble and new ones outlive the initial period during which the effects of neglect are barely perceptible.

The cost of restoring these deteriorated roads is going to be three to five times greater than the bill would have been for timely and effective maintenance—and restoration is only part of the cost. Vehicle operating costs rapidly outpace the costs of road repair as the condition of roads passes from good to fair to poor. Together, these avoidable costs are going to form a formidable obstacle to further economic development.

The Repair Bill for the Next Ten Years: $90 Billion or Much More?

In the eighty-five countries that have received World Bank assistance for roads, a quarter of the paved roads outside urban areas need reconstruction—as do a third of the unpaved roads. This work will cost $40 billion to $45 billion. (Timely preventive measures costing less than $12 billion could have saved these roads and held down the operating costs for road users.)

In addition, another 40 percent of the paved roads in these countries require strengthening today or will in the next few years. This work, along with routine maintenance, will cost another $40 billion to $45 billion over the next ten years. That brings the total bill for these countries to about $90 billion. But if these countries do not improve their management of roads, the eventual cost of restoration could easily increase two- to threefold, and the cost to users would rise even more.

What Caused the Deterioration?

In the 1960s and 1970s road networks expanded much faster than the corresponding maintenance budgets and institutional capacities. Traffic has also become much heavier than expected, and axle loadings have often exceeded the designed capacity of pavements. These patterns are evident almost everywhere. Less evident is what has been happening to the roads.

New paved roads, if inadequately maintained, deteriorate slowly and almost imperceptibly during the first half to two-thirds of their service life, depending on the traffic. After that grace period, which may last ten to fifteen years, the pavements deteriorate much more rapidly. Without timely maintenance they break apart.

As roads become rougher, the costs of operating vehicles—and of transporting goods—begin to shoot up. The neglect of maintenance continues, however, because it is the vehicle operators that pay these costs—and pass them on if they can. Road authorities are not directly affected by these costs, and they come under no immediate pressure to improve road conditions. Road users are often slow to see the link between road conditions and the prices of goods and transport services—and are usually not organized to do something about it.

In the absence of public pressure and lacking a clear understanding of the seriousness of the problem, few governments have given road maintenance a high priority in their budgets. The urgency of the situation has not always been fully appreciated by all donors and lending agencies, some having been readier to provide funds for new construction than for maintenance and restoration. New construction has sharp political visibility, maintenance little glamour. Inadequate maintenance in developing countries has various causes, but institutional failure is the only explanation for its wide extent. At the heart of this failure is the absence of public accountability.

The Requirements for Efficient Restoration

The task now facing many developing countries—as well as the World Bank and other aid agencies—is to salvage roads that have deteriorated severely and to protect newer roads from a similar fate. This task has large financial, technical, and institutional requirements. Of these, the institutional requirements are the most pressing.

The technical options today seem richer. Thanks to recent empirical research that has broadened our understanding of the physical process of road deterioration, we now know of ways to keep roads serviceable at lower cost than before. The financial requirements, however, are steep. Some countries will require large infusions of external capital; all will need political resolve to mobilize resources at home. But additional financial resources alone will not ensure effective restoration and preservation of roads, nor will they prevent a recurrence of the kind of crisis and waste so evident today. Needed above all is a reform of the institutional base of the road sector. Accountability must be stronger in all entities and activities that maintain public assets. Public and political attention must be deliberately fostered. The organization, manning, and activities of the institutions looking after roads must be improved to increase their absorptive capacity.

Technical Requirements

Standard engineering practices have very different effects in different environments. Road investment and maintenance strategies must therefore be tailored to the circumstances of individual countries. Nevertheless, some general guidance can be offered in light of our growing understanding of the causes, process, and effects of road deterioration.

For one thing, the savings in vehicle operating costs from paving lightly traveled roads are less than previously estimated. Furthermore, the total life-cycle transport costs on paved and unpaved roads are nearly the same over a wide range of traffic volumes (typically 150–400 vehicles a day), as long as the roads are reasonably maintained. Big differences in cost arise only if maintenance is not done or is deferred. If the availability of funds for future upkeep of paved roads is uncertain, it is economically safer to keep lightly traveled roads unpaved and reasonably maintained.

It also makes sense—in times of budgetary stringency when road allocations are not too far below the optimum—to consider alternative maintenance strategies. Some strategies that involve small cuts in spending barely affect the costs to road users. Others, although similar in amount, can drive up user costs substantially. Still other strategies, involving much deeper cuts, can multiply the future cost to both the road agency and the user—so much that they are self-destructive. For example, if the budget cuts are so large that they preclude the resurfacing or strengthening of the paved roads that are now in fair condition, these roads will soon fail structurally and require much more costly restoration. This, regrettably, is the situation in many developing countries, and it will soon spread to many more.

Here are some of the technical choices that each country should examine in light of its needs and capabilities:

- Gravel roads should be paved only after a complete analysis of the costs, climate, present and future traffic, and reliability of future maintenance.
- If the volume of traffic indicates that paving is advisable, the choice of pavement strength should be guided by the likelihood of undermaintenance and excessive axle loads. If the likelihood is high, pavements should be built to the required strength immediately rather than in stages. The cost will, of course, be higher, so that a given budget for new construction will yield fewer kilometers of new road.
- Deterioration of paved roads is gradual and barely perceptible during a long initial phase that lasts up to two-thirds of the pavement's life cycle. Resurfacing and strengthening can thus be deferred somewhat—as long as the roads remain in

fair condition and have not entered the critical phase of their life cycle. Longer deferral will cause pavements to break up. The stage of a paved road in its life cycle must therefore determine the decision to defer resurfacing and strengthening operations.

- Traffic is critical for maintenance decisions. If funds are tight, it may be best to keep heavily traveled roads in fair or good condition and to reduce substantially the maintenance of roads with light traffic. Even if funds are not tight, it may make little economic sense to fully restore paved roads that are lightly traveled. If funds are very tight, it may be best to let lightly traveled roads deteriorate further and perform only minimal routine maintenance to keep them usable.

Institutional Requirements

The inadequacies of road maintenance stem in part from the structure and functions of the traditional road agency. Often a public monopoly, the agency has too many responsibilities—for planning, controlling, and executing both construction and maintenance. The agency typically devotes too many staff, funds, and facilities to execution—to the detriment of planning, control, and evaluation. This makes it desirable in many countries to separate the execution of works from the other functions by lodging it in the private sector or in a separate government agency. Where this separation has succeeded, the incentives for good performance have been strong and the delineation of accountability clear.

A road agency also needs an effective management information system to monitor traffic, road conditions, and (just as important) its internal workings. The agency should be equipped to analyze the life-cycle costs of construction and maintenance and the present and future cost to users. Testing alternative design and maintenance policies for their sensitivity to different discount rates, traffic loads, and other variables may be helped by computer models. But even less sophisticated methods to plan investments and maintenance will be unworkable without a reliable data base and capable staff.

The road agency should, above all, introduce mechanisms to increase the internal accountability for performance and for resource use—and to provide incentives for good performance in the agency and by the contractors it engages. It should, moreover, work with the media and with nongovernmental organizations to make the political leadership and the public aware of the effects and high costs of failing to maintain the roads.

Financial Requirements

The present bill for repair and maintenance is about $90 billion, or $9 billion a year for the next ten years. That could arrest future deterioration and clear up the backlog of economically warranted restoration. If the work were to be finished in five years, however, the total cost, again without discounting, would come down to less than $70 billion, or about $13.5 billion a year. (Road spending in 1984 was about $13 billion, but only half of this went for restoration and maintenance.)

These aggregate sums obscure wide differences from country to country. The sixty-one developing countries that have data on road spending fall into three categories of capability—with about a third in each. First are the countries that could meet future maintenance requirements and eliminate their backlogs in five years without increasing their total spending on roads, but only by holding back on new construction and allocating up to 80 percent of their total spending to restoration and maintenance. Next are the countries that could do the same in ten years, but only by raising their spending for those years by 50 percent and by allocating 80 percent of that total to restoration and maintenance. Last are the countries that would have at least to double their spending, even if they devote all of it to restoration and maintenance.

To justify more spending on roads and its reallocation to restoration and maintenance, each country will have to perform a systematic analysis to determine how much should be spent on roads—and how. Some countries may choose to revise user charges or impose new ones, which if translated into better roads can reduce rather than increase vehicle operating costs. Some may decide that to avoid misallocations they will have to earmark budgeted funds for restoration and maintenance, especially the funds that might be raised through a temporary surcharge. Others will have to rely heavily on external sources of finance.

Implications for the World Bank

Economic losses—actual or potential—caused by inadequate road maintenance can have important implications for the Bank's macroeconomic dialogue with its borrowers, particularly in the context of public expenditure priorities. The evidence in this study suggests that in several countries the economic returns from spending more for road maintenance would justify a substantial expansion of such expenditures relative to outlays for new road construction.

An expansion in total expenditures on roads relative to other sectors could also be warranted in some countries. That determination, however, can be made only by a comprehensive review of public expenditures which evaluates the comparative benefits of proposed outlays in all major sectors.

The developing countries differ according to their need to expand and improve their road maintenance organizations and procedures, their need to increase their total road budgets and make reallocations from construction to maintenance, and their need for external assistance. In addition, some have obsolete networks, others new ones. These differences suggest several distinct categories of need for external assistance in the road sector. The Bank's lending for roads should be tailored to the circumstances in each category—and be made conditional on an acceptable distribution of road expenditures for maintenance, restoration, and new construction.

- For countries with the best performance (category I in the text)—largely but not exclusively upper-middle-income countries—the Bank will view itself mainly as a vehicle for institutional and technological improvements. It will nevertheless extend funds for balanced programs of maintenance and new construction.
- For countries in which road maintenance is inadequately funded (category II)—including a substantial number of middle-income countries—the Bank will provide external finance mainly for maintenance and restoration. Such finance will be linked to policy and institutional reforms.
- For countries with severe financial and institutional constraints on maintenance (category III)—almost exclusively low-income countries—the Bank's assistance over the next few years will be devoted with few exceptions to maintenance and restoration. The assistance will be conditional on institutional reforms and on the allocation of road budgets exclusively to maintenance and restoration (with only limited and defined exceptions).
- For countries with obsolete roads, technology, and organization (category IV), the Bank will emphasize organizational and technological improvements in modernizing the road networks and will also support new construction when it is justified.

In all this, the Bank will encourage the execution of maintenance work by entities outside the road authority—entities operating on commercial principles, preferably in a competitive environment. In addition, the Bank will promote measures to increase public awareness of the need for timely maintenance and of the high cost of neglecting roads.

The Bank will also promote more coordinated action by the international community in dealing with the growing problem of road deterioration in the developing countries. To this end the Bank will work closely with other aid agencies in designing road programs appropriate to the needs of each country (along the lines of the four categories spelled out above). The Bank will also work closely with other aid agencies in supporting research on roads—work that would be done mainly by road agencies and road research institutions in the developing countries. The emphasis in these efforts will be on international exchanges of data, technology, and management information systems. The Bank will support compilation and publication of statistics on roads—work that should be undertaken by the United Nations Statistical Office or an organization such as the Permanent International Association of Road Congresses or the International Road Federation. External agencies should provide financial assistance for this effort.

The recommendations for World Bank policy emerge from a view of the root causes of road deterioration in countries where it is now severe. We know now that some past investments have been mistakes. We know, too, that deterioration reveals its symptoms late and gives little warning of what is to come. Added to these factors are the civic calamity in some countries and the harsh and prolonged economic adversity in many more. But where the road problem is now serious or is about to turn serious, the damage attributable to such factors could usually have been mitigated by more efficient institutional arrangements for the management of the country's infrastructure. It is difficult to understand fully the causes of institutional failure in different countries—and even more difficult to prescribe countermeasures guaranteed to cure the problem. But this is no case for leaving things as they are. Action is required, even if it has to be accepted as experimentation. Bank support for the road sector of countries with serious road deterioration problems will therefore be guided by signs of institutional progress. These signs include the growth of political attention to the preservation of infrastructure, the strengthening of internal accountability in the institutions charged with managing it, the introduction of incentives that press people to perform, and the deliberate search for resources and schemes that promise care for hard-won national assets.

1

The State of the Roads

The developing world's road building boom in the 1960s and 1970s created an infrastructure that has been crumbling in the 1980s and threatens to collapse in the 1990s if not quickly strengthened and protected. Large road networks, built at great expense, have been inadequately maintained and used more heavily than expected. The result in many developing countries is a network of deteriorating roads. Many roads are in such poor condition that normal maintenance is no longer sufficient or effective. These roads now require rehabilitation or reconstruction at three to five times the cost of timely preventive maintenance and strengthening. And many more roads, whose deterioration is not yet visible, will soon reach that point if they are not better maintained.

The problems of poor maintenance are worse for roads than for other sectors for three reasons:

- *The costs and financial requirements are large.* For example, expenditures to compensate for past omissions in preventive maintenance in Sub-Saharan Africa are at least ten times those of supplying textbooks for all elementary schoolchildren in the region until the year 2000.
- *Road deterioration accelerates with time.* This phenomenon makes it difficult, but also all the more important, to recognize the need for preventive maintenance before deterioration becomes obvious and more expensive rehabilitation or reconstruction becomes necessary.
- *Road authorities are insulated from the effects of undermaintenance.* The agency responsible for road maintenance usually is not exposed to either the economic consequences of undermaintenance or the organized pressure for better roads and thus has little incentive to provide responsive, effective maintenance.

The costs to road authorities are only the tip of the iceberg, for the costs to road users operating vehicles on rough roads are much larger. High haulage costs constrain the location of economic activity, hamper the integration of economic markets, limit the gains from specialization, and render unviable many activities that rely on road transport (see box 1-1).

An Overview of Road Conditions

This study assesses road deterioration in the eighty-five developing countries receiving highway sector assistance from the World Bank—officially, the International Bank for Reconstruction and Development (IBRD) and its affiliate, the International Development Association (IDA). The analysis covers only the main road networks, both because they are the most important roads and because information on other roads is fragmentary. In these countries 70 to 80 percent of interurban traffic is on the main networks. These networks consist of 1.8 million kilometers of primary and secondary roads (of which 1.0 million kilometers are paved) and have a replacement value of about $300 billion, excluding the value of land, bridges, and major earthworks (see table A-1 in appendix A). The main networks generally include

Box 1-1. The Consequences of Road Neglect in Ghana

Road deterioration can make an economic crisis worse. In Ghana a good road network was built before 1970, but it later suffered from serious neglect. By 1984 about 60 percent of the main paved roads were in a state of moderate to severe deterioration. Important sections have become almost impassable, and access to some interior areas has been severely curtailed. Transporters refuse to go there because they do not want their vehicles to break down.

Transport costs have increased in real terms by about 50 percent on main roads and by more than 100 percent on rural roads, which have suffered even greater neglect. In many areas the market rate for transporting fertilizer is as high as a dollar per ton-mile. These high costs have cut deeply into farm returns, particularly for poor farmers in areas away from main roads: some villagers can no longer move their cocoa stocks to regional depots. And during the 1982–83 famine poor roads prevented the transport of food from surplus areas to areas facing starvation. The high cost of transport has also hit the timber industry. Logs moving from the Kumasi area for export through the Takoradi Port are trucked over a 500-kilometer route because the direct road, which is about half as long, is broken down and the rail services are unreliable. The detour adds $15 to $20 for each ton of logs exported.

The prospects are not encouraging. The resources needed for road resurfacing and strengthening (mainly to reseal 1,100 kilometers of paved roads and regravel 1,600 kilometers of unpaved roads) constitute only about 20 percent of the sector's total annual requirements, which are estimated at $47 million. Even with a recent road maintenance project supported by the World Bank, the allocation for maintenance will increase only to about 30 percent of what is needed by 1989. Unless more resources can be put into road maintenance—and applied effectively—deterioration will continue. If so, it will take far more costly rehabilitation to forestall the almost total collapse of road transport in Ghana.

the principal roads and highways that cross urban areas or provide access to ports. The analysis does not deal with urban roads; nor does it cover 5 million to 6 million kilometers of rural roads and tracks (most of which are unpaved and lightly traveled) with a replacement value of perhaps $75 billion to $100 billion (Faiz, Harral, and Johansen 1987).

Detailed assessments of road conditions are subject to considerable error. The importance of systematic monitoring and evaluation of road conditions has only recently become generally recognized, and few developing countries have data bases and management information systems that are adequate to the task. Nevertheless, the evidence is good enough to show the broad dimensions of the problem. Recent field surveys, supplemented by the judgment of World Bank engineers, make it possible to distribute a country's roads among three classes of condition: good, fair, and poor (Mason 1985; Mason and Miquel 1986). A road in good condition requires only routine maintenance to remain that way. A road in fair condition needs resurfacing. A road in poor condition has deteriorated to the point that it requires either partial or full reconstruction (see the glossary at the front of this book for definitions of the various types of road maintenance and improvements).

Three facts about road deterioration help to clarify the problem. First, because reconstruction costs three to five times as much as resurfacing or rehabilitation, no road should be allowed to decline into poor condition unless it is to be kept in that condition deliberately (with routine maintenance but no resurfacing or rehabilitation) or abandoned entirely. Second, normally there is a period of about five to eight years during which paved roads in fair condition can be restored by resurfacing or strengthening; after that time more costly measures become necessary. The existence of many roads in fair condition suggests, therefore, that extensive maintenance is needed quickly if these roads are to be saved before they decline to poor condition. And third, the cost of operating vehicles (especially large trucks) rises as roads deteriorate. Because vehicle operating costs are the largest part of transport costs on all but the most lightly traveled roads, the increase in operating costs swamps all other costs at stake in road management as roads deteriorate.

Based on regional averages, road conditions in the countries studied are alarming on two counts (see table 1-1). First, more than a fourth of all paved roads—some 269,000 kilometers—are already in poor condition and need rehabilitation or reconstruction. Second, the heavy concentration of paved roads in fair condition (42 percent) foreshadows a major crisis unless concerted efforts prevent these roads from deteriorating into poor condition. Less serious deterioration in the 1970s in the U.S. network of highways receiving federal aid prompted widespread alarm, new legislation, new user taxes, and a large

Table 1-1. Condition of Main Roads, by Region
(percent)

Region	Paved			Unpaved		
	Good	Fair	Poor	Good	Fair	Poor
Eastern and Southern Africa	42	32	26	42	30	28
Western Africa	52	23	25	20	36	44
East Asia and Pacific	20	59	21	41	34	25
South Asia	19	45	36	6	39	55
Europe, the Middle East, and North Africa	41	35	24	30	46	24
Latin America and the Caribbean	44	32	24	24	43	33
Average	32	42	26	31	36	33
United States (Federal Aid Network, 1981)	31	57	12	–	–	–
United Kingdom (Trunk Road System, 1983)	85	12	3	–	–	–

— Not applicable.
Note: The percentages are weighted by the length of the main road networks in each country in the regions.
Sources: For the United States, U.S. Congressional Budget Office (1983), pp. 20–21; for the United Kingdom, U.K. National Development Office (1985), p. 9; for the six regions, World Bank survey of eighty-five countries that was based, as far as possible, on published information about pavement conditions in sixty of the countries and supplemented, where necessary, by the judgment of Bank highway engineers. See the glossary for definitions.

infusion of federal and state resources in the 1980s (Baker 1984; U.S. Congressional Budget Office 1983).

The unpaved roads in the main networks are even worse. True, the timing of maintenance for unpaved roads is less critical than for paved roads because the costs of restoring unpaved roads are less sensitive to the timing of the intervention. Even so, however, the aggregate effect of their deterioration on vehicle operating costs can be considerable. Although unpaved roads normally carry much less traffic, the ride quality of an unmaintained unpaved road deteriorates many times faster than that of a paved road (except in the terminal phase of the paved road's life cycle). Deferring routine maintenance on unpaved roads can quickly double the vehicle operating costs.

Major Determinants of Road Conditions

The considerable variation in road conditions from country to country and region to region stems from differences in the past maintenance needs of individual networks and the countries' responses.

Need for Maintenance

The maintenance needs of a road network can be predicted fairly accurately from a set of structural characteristics, such as age, climate, traffic, design standards, construction quality, and subsequent maintenance. Of these, age, traffic, and construction quality are of particular importance in the developing countries.

Age is important to the condition of paved roads because of the time path of their deterioration. Typically, two-thirds of pavement deterioration (and an even higher proportion of maintenance cost) is concentrated in the final third of the design life of the pavement (see chapter 2). After a boom in road construction, a grace period of several years—during which roads remain in good condition even without maintenance—is followed by a period in which the need for maintenance surges dramatically.

Differences in the age of networks underlie the regional differences shown in table 1-1. On the whole, paved roads in Western Africa are in better condition than the roads elsewhere. The networks in Western Africa are fairly new: more than half the paved roads were constructed, upgraded, or reconstructed in the past ten years.

Nigeria and Côte d'Ivoire have substantially rebuilt their paved networks since 1975 (see box 1-2). Other less well-endowed countries in the region were helped by external aid agencies to develop and improve their road networks. Of twenty countries in Western Africa for which information is available, fifteen have young networks. The proportion is not much lower in Eastern or Southern Africa, where ten of sixteen paved networks are fairly new. Without substantial external assistance, however, many of these networks are unlikely to remain serviceable beyond the next ten years.

The growth of traffic on roads built to obsolete standards helps to explain the general condition of the roads in South Asia: only 19 percent of the paved roads remain in good condition, and 36 percent are

Box 1-2. Nigeria's New Roads and the Risk of Massive Deterioration

Of the 21,000 kilometers of paved roads in the Nigerian federal trunk road system, 36 percent were constructed or rehabilitated in 1975–80 and another 24 percent in 1981–85. As a result 62 percent of the network is rated good, 15 percent fair, and 23 percent poor. Neglect of the unpaved network has rendered an estimated 90 percent of unpaved roads in poor condition.

Despite the remarkable expansion and improvement of the Nigerian trunk road system in the past ten years—at an estimated cost of $8 billion—the situation is still precarious. Many of the roads were built with generous geometric features but weak pavements, which require substantial strengthening. Without an extensive program to resurface and strengthen about 2,000 to 3,000 kilometers of pavement a year, at an estimated annual cost of $150 million to $200 million, the Nigerian trunk road system may deteriorate rapidly and require massive rehabilitation and reconstruction in the next ten to fifteen years.

in poor condition. South Asia's road networks consist mainly of aging roads with neither the geometric capacity nor the structural strength to carry current traffic. Both the volume of road traffic and the axle loads have increased over the past decade as economies have grown and traffic has shifted from other modes. Many of the roads in these networks need upgrading in addition to normal maintenance and rehabilitation. Countries in South Asia, particularly India, face the need for a very large program of road building.

The age of networks and the growth of traffic explain some differences in maintenance requirements, but the present condition of the roads reflects the extent to which maintenance requirements have been met in the past. Inadequate maintenance is largely the result of misallocated funds, unsound maintenance strategies, and inefficient implementation.

Financial Capacity

The capacity to pay for road maintenance from domestic sources depends on a country's resources. Gross national product (GNP) per capita may thus be a good index of financial capacity, but some governments are able to capture more of it than others. And of the fiscal intake, the allocation to highways is a political decision about national priorities. Variations in income growth also affect funding: severe setbacks in income growth clearly explain some important instances of underfunded maintenance and consequent road deterioration.

Road conditions in Latin America are worsening rapidly, mirroring the general economic downturn and accompanying financial stringencies of the past five years—and illustrating how quickly roads can deteriorate once they reach the critical age. Brazil, the country with by far the largest road network in Latin America, has seen serious erosion despite substantial efforts. In 1984, 28 percent of the network was in poor condition, up from 18 percent in 1979 (see box 1-3). The deterioration was even more dramatic in Honduras, which had previously had adequate road maintenance. The percentage of the paved roads in good condition there dropped from 82 percent in 1981 to 50 percent in 1984, largely as a result of financial constraints.

A broad indicator of the economic burden of road maintenance is the ratio of the length of a country's road network to gross national product, with an allowance for the lower traffic volumes in poorer countries. The ratio for main roads ranges from 0.3 kilometer per million dollars of GNP for the Republic of Korea and 0.4 for Nigeria to more than 8.0 for Botswana and Zaire and 14.5 for Guinea-Bissau. Of the thirty-six countries with the highest ratios, thirty-two are in Sub-Saharan Africa (see table A-2 in appendix A). Even with the best management, these countries would still face the world's highest burden of road maintenance requirements relative to income and would be likely to have lower than average levels of maintenance.

Financing road maintenance by borrowing from commercial sources abroad or development institutions could help to fill the funding gap, but many of these sources have preferred to finance construction rather than maintenance.

Institutional Capacity

The foregoing indicators—the differences in GNP per capita and its rate of change, the ratio of network length to GNP, the age distribution of roads, and the volume of traffic—do not fully account for the variation in road conditions from country to country. Several higher-income developing countries have poor roads, and some of the lowest-income countries

Box 1-3. A Case of Undermaintenance: Brazil's Federal Highway Network

A 1979 survey of Brazil's federal highway network showed the following distribution of road conditions:

	Kilometers	*Percentage of network*
Good	10,000	24
Fair	23,000	58
Poor	7,000	18

Restoration and preventive maintenance of all roads at that time would have cost $1.8 billion in constant prices. A repeat survey in 1984 rated the network as follows:

	Kilometers	*Percentage of network*
Good	14,000	30
Fair	19,000	42
Poor	13,000	28

The increase in the percentage of roads in good condition was the result of new construction, not good maintenance: 6,000 kilometers of new paved roads were constructed, while 2,000 kilometers of those formerly in good condition declined to fair. Nor did the massive backlog of roads in fair condition receive the resurfacing or strengthening that was due. Some 6,000 kilometers of that group deteriorated to poor condition, which greatly increased the number of kilometers and the percentage of roads needing rehabilitation or reconstruction rather than just preventive maintenance. The cost of this restoration is estimated at $1.7 billion, and the cost of the preventive maintenance needed to save the roads still in fair condition is estimated at $750 million. Thus the federal rehabilitation and maintenance backlog grew to $2.4 billion, a one-third increase in six years.

have better ones. The capacity of a country to deal with its maintenance needs also depends on how effectively and efficiently it can use funds to protect and rehabilitate the road infrastructure—a factor generally known as institutional capacity.

Institutional capacity has several facets. One is the pool of skills, such as the size of the labor force, that can be applied to the activity. Others are the soundness of the maintenance strategy—type, level, and timing of intervention—and the managerial and operational efficiency with which the strategy is executed. These depend, in turn, on such factors as government commitment, institutional structure, managerial ability, staff quality, accountability, and incentives. Experience with these aspects of institutional capacity has often been remarkably disappointing. And where limited institutional capacity cannot readily be expanded, the prospects are poor for recovering infrastructure that has already deteriorated or, if the peak of maintenance needs is yet to come, for preventing heavy losses of capital.

The Hard Core of the Problem

Not all countries facing a maintenance crisis have arrived there by the same trajectory. Some have backlogs of maintenance needs because their financial and institutional capacities have not expanded as fast as their road networks. Some have built up backlogs by deferring needed maintenance during adverse economic conditions. Some do not appear to have backlogs now, but their networks of relatively recent construction will soon require greatly increased and systematic maintenance to prevent rapid deterioration. The road deterioration problem thus pervades the developing world. At the core of the problem are mainly the countries of Sub-Saharan Africa and South Asia, and at the hard core of the problem are those Sub-Saharan countries whose financial and institutional capacities are unequal to the task at hand or to the one they will soon have to face.

Although some networks in Sub-Saharan Africa (Côte d'Ivoire, Malawi, Niger, and Rwanda) are among the better maintained, they are also of recent vintage and will soon require much more maintenance as the paved roads pass into the critical stage. In the rest of Sub-Saharan Africa, recently expanded networks are also numerous and therefore in better condition than older ones. In ten countries with older networks, an average of 44 percent of their paved road length is in poor condition: in the seventeen countries with fairly new paved roads, the proportion of poor roads is only 22 percent. There is, however, no reason to believe that countries with newer paved networks have better capacities or policies for road maintenance than those with older networks. If they did, their unpaved roads should be in better condition; for without maintenance, unpaved roads deteriorate rapidly and at a uniform rate. The condition of unpaved roads in countries with newer paved roads differs little from that in countries with older paved roads. So the state of a country's paved roads, by itself, says little about the country's maintenance capacity.

In many countries the rapid expansion of networks has outstripped the growth in institutional capacity

Box 1-4. The Construction-Maintenance Tradeoff: Consequences for the Road Network

The tradeoff between construction and maintenance and its implications for the road network can be explained by a simple construct. Consider a main road network of 1,000 kilometers of paved roads that requires an annual budget of $6 million, or $6,000 per kilometer—$1.5 million for routine maintenance (at $1,500 per kilometer per year) and $4.5 million for resurfacing (at $45,000 per kilometer every ten years, or $4,500 per year). The average estimated remaining life of paved roads with little or no maintenance is ten years. If this budget is partly used for new construction (at $240,000 per kilometer) to extend the road network by 1 percent each year, the following results will emerge:

- Annual increase in road length: 10 kilometers
- Annual construction cost: $2.4 million
- Balance of budget remaining for maintenance: $3.6 million
- Length of road that can be annually maintained and resurfaced with the residual budget, at $6,000 per kilometer: 600 kilometers.

If this construction-maintenance policy continues for ten years, 100 kilometers of new paved roads will have been built, but lack of maintenance during this period will have rendered 400 kilometers unserviceable, because only 600 kilometers can be adequately maintained with the residual maintenance budget. The rehabilitation bill for these 400 kilometers at the end of ten years would amount to some $70 million, at an average cost of $175,000 per kilometer. Thus over a ten-year period the road network will suffer a net dimunition of 300 kilometers: the gain of 100 kilometers of new roads as against a loss of 400 kilometers of existing roads through lack of maintenance.

This analysis (adapted from Robinson 1987) assumes that the funds available for maintenance and resurfacing are concentrated on a restricted length of 600 kilometers. If the funds were instead spread across the entire network, the loss of serviceable roads would likely be even greater.

for road maintenance. The full consequences of this lag are not yet evident in most paved networks, because most of the roads are still in the grace period during which they need little maintenance and show few signs of deterioration even when maintenance is neglected. Prolonged undermaintenance, however, can eventually result in a net diminution of the road network (see box 1-4).

The effects of undermaintenance are already reflected in the relatively poorer condition of unpaved roads in all regions. In Nigeria 62 percent of the paved roads are in good condition, whereas none of the unpaved roads are rated as good. In Côte d'Ivoire 78 percent of the paved roads, but only 30 percent of the unpaved roads, are classified as good. Both countries developed their paved networks fairly recently, so their maintenance requirements will grow significantly in the next few years. Almost every region has some countries in or approaching crisis, but Sub-Saharan Africa stands out as having the most countries at the hard core of the road deterioration problem.

2

Technical Options and Their Economic Consequences

A few fundamental relationships explain road deterioration and its consequences for the total cost of road transport. They hold true in a wide variety of environments and form the starting point of any rational maintenance plan. Recent research has greatly clarified these relationships and has quantified and refined them empirically. As a result, economical maintenance strategies can be designed for a wide range of circumstances, and the error of certain strategies can be seen. Above all, these relationships and the new data make it possible to provide firmer guidance for countries that have to restore badly deteriorated parts of their networks while keeping the other parts serviceable.

Economic decisions about a highway system must take into account the total cost of transport on the roads: the discounted life-cycle cost of constructing and maintaining the roads and the (usually) far larger cost of operating vehicles on these roads. These costs must be estimated on the basis of sound knowledge about road and traffic conditions and the interactions between them, as well as the applicability of different maintenance techniques in different environments.

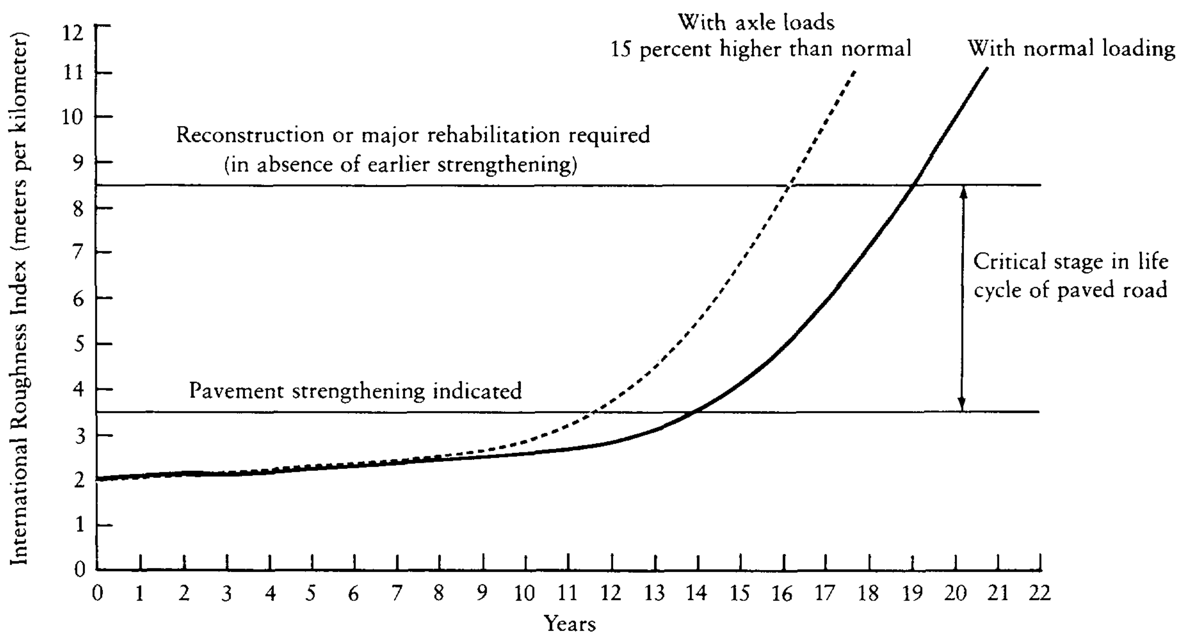
The Fundamental Relations

As roads deteriorate they get rougher. Until recently roughness was assessed subjectively, but now it can be quantitatively evaluated using measures such as the International Roughness Index (IRI) (Sayers, Gillespie, and Paterson 1986). Unpaved roads, if not maintained, deteriorate rapidly and at a fairly uniform rate throughout their life cycle. But unmaintained paved roads follow a distinctly nonlinear path. (All references in this chapter to the absence of maintenance assume that the minimal work of vegetation control and drainage clearing is carried out. These low-cost activities are vital to the continuing serviceability of roads, and neglecting them is a sure way to hasten road deterioration.)

During a long initial phase that lasts up to two-thirds of their life cycle, paved roads undergo little visible deterioration. This is followed by a phase of increasing—and increasingly rapid—deterioration (into fair condition) that ends within a few years in radical structural failure (poor condition). This nonlinear path of deterioration affects the choice of the optimal maintenance policy for paved roads (see figure 2-1). For the unwary it also tends to disguise the future maintenance requirements of young networks.

During the first phase a paved road can be kept in good condition with fairly inexpensive routine maintenance. In the subsequent phase of increased deterioration, the pavement can be restored to good condition by resurfacing or, at a moderate cost, by adding an overlay. An overlay will restore the ride quality of the road, make the pavement strong enough to meet traffic requirements for the next several years, and thus start a new pavement cycle. With adequate routine maintenance and timely resurfacing or strengthening, a paved road should not

Figure 2-1. Deterioration of Paved Roads over Time



Note: Data are based on the following assumptions: asphalt concrete pavement (structural number = 3.5); average daily traffic = 2,500 vehicles; rainfall = 120 millimeters a month; minimal maintenance.

deteriorate into poor condition or require reconstruction.

Another fundamental relation links vehicle operating costs to road roughness (see table 2-1). Recent research has shown that roughness has less of an effect on vehicle operating costs than previously estimated. The new estimates are, on average, a quarter below those proposed in an earlier standard work (see appendix B). Overestimates of the savings in vehicle operating costs may have led to faulty investment and maintenance decisions, but a far graver error occurs when maintenance policy ignores the share of vehicle operating costs in the total cost of road transport. That share is high, except where traffic is extremely light (see figure 2-2). Even a small percentage increase in vehicle operating costs from rougher roads will outweigh the cost savings from deferring maintenance.

Table 2-1. The Effect of Road Roughness on Vehicle Operating Costs
(Index of vehicle operating costs: good = 100, at 2.3 IRI)

	Road condition[a]	
Vehicle class	*Fair (4.6 IRI)*	*Poor (6.9–9.2 IRI)*
Small car	106	114–26
Bus	104	109–16
Light diesel truck	111	124–38
Heavy truck	114	129–46
Articulated truck	112	127–44

Notes: Data are based on 1984 economic costs for Costa Rica.

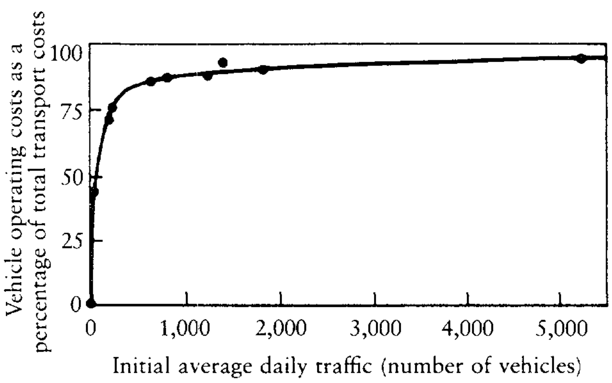
a. The dominant effect of road condition on vehicle operating costs is through "roughness," a measure of road surface irregularities standardized by the International Roughness Index (IRI).

Source: From application of the vehicle operating costs submodel of the Highway Design and Maintenance Standards Model (HDM-III). For the Costa Rican context, see Bhandari and others (1987).

Strategies for Road Investment and Maintenance

Much information about the process and effects of road deterioration comes from empirical research supported by the World Bank (see box 2-1). The large data set represents an important contribution to the effort to design cost-effective road strategies—especially ones combining construction and maintenance policies—for developing countries. A model based on that research has been used in studies of road maintenance in several countries, including Chile, Costa Rica, and Mali, which as a group exemplify a wide range of transport conditions found in the developing world (see appendix B). These studies demonstrate the interdependence of investment and maintenance decisions and the role of information on road conditions, traffic, and traffic growth in ensuring decisions with satisfactory outcomes. The results, although specific to the conditions in the countries studied, illustrate general points about the selection of cost-effective maintenance policies and the criteria for deciding whether or when to pave and what pavement strength to choose. An annual discount rate of 12 percent is used for the analyses reported in this chapter (Bhandari and others 1987).

Figure 2-2. Vehicle Operating Costs as a Percentage of Total Life-Cycle Transport Costs for Typical Cases with Optimal Maintenance



Note: Traffic is assumed to grow at 3 percent a year. The present value of road construction and maintenance costs + vehicle operating costs is computed with a discount rate of 12 percent.

Traffic and Road Conditions

In establishing standards for road design and maintenance, the key factor is the level of actual and expected traffic. For Chile and Costa Rica, which have relatively high volumes of traffic on their road networks, the optimal policy was to keep the most heavily used two-thirds of the networks in good condition while maintaining the other third at lower standards. In contrast, the most economical solution for Mali, where traffic volumes are generally low, was to keep about 1 percent of the network in good condition and maintain the rest at reduced standards as determined by traffic.

Under these optimal policies, keeping roads in less than good condition does not imply neglecting maintenance. In all cases drainage and vegetation control are fundamental, as are high standards of patching and basic routine maintenance, even for

Box 2-1. The Highway Design and Maintenance Standards Study

In 1971 the World Bank initiated what later became a major collaborative program of primary data collection and research—first in Kenya and later, on a much larger scale, in Brazil and India. More than $20 million was spent to collect and analyze data on highway conditions and vehicle operating costs so that key relationships linking road construction, maintenance, and vehicle operating costs on different roads and under different road conditions could be quantified. More than 90 percent of the funds came from the other participants: the governments of Brazil, India, Kenya, and the United Kingdom, as well as the United Nations Development Programme. Australia and Sweden provided technical assistance.

Results of the studies are reported in a series of World Bank publications, including two volumes on road user costs (Chesher and Harrison 1987; Watanatada, Dhareshwar, and Lima 1987), a volume on road deterioration (Paterson 1987), another on the planning model (Watanatada and others 1987), two technical papers on measuring road roughness (Sayers, Gillespie, and Paterson 1986; Sayers, Gillespie, and Queiroz 1986), and a technical paper on evaluating traffic capacity and improvements to road geometry (Hoban 1987). This research advanced our understanding of the links between road deterioration and vehicle operating costs beyond the state of ten or fifteen years ago. It revealed the complexity of the relations—which were formulated on the basis of a more comprehensive data set than was previously available—and their sensitivity to an array of area-specific circumstances.

To apply this empirical knowledge to the related questions of highway construction and maintenance, the World Bank developed the Highway Design and Maintenance Standards Model and a companion Expenditure Budgeting Model. These models search for the best solution appropriate to a country's circumstances by exploring the effect of multiple combinations of road design and maintenance options on total transport costs. The results can then be tested for sensitivity to variations in input parameters and future conditions—a necessary precaution. Successful application of either model, however, depends on the reliability of the information system and the ability of staff to use the data base and the model properly.

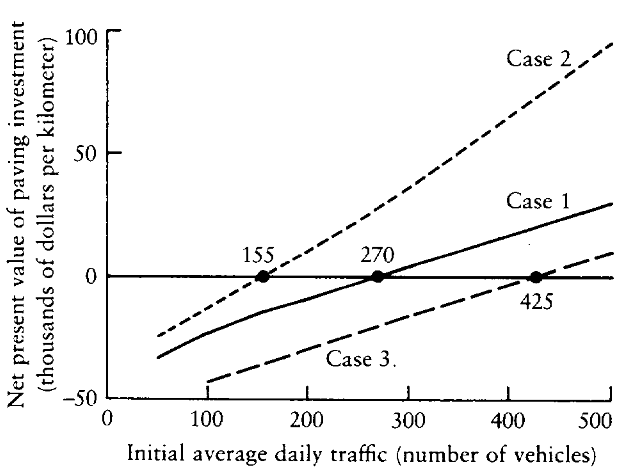
roads to be maintained at low standards. In Mali this maintenance is estimated to cost $6.2 million a year—about twice the current spending. This estimate, however, does not include the $9 million required to rehabilitate and reconstruct the backlog of higher-volume paved roads in poor condition that warrant saving.

To Pave or Not To Pave

Decisions about whether and when to pave a road must take many factors into account, including the expected growth in traffic. Figure 2-3 shows, for a specific example in Mali, the net present value of paving a gravel road as a function of traffic. Comparison of cases 1 (no growth in traffic) and 2 (6 percent annual growth) indicates that the traffic level at which it becomes optimal to pave the road is sensitive to the expected rate of traffic growth. It is assumed in all cases that proper maintenance will be carried out whether the road is paved or not. The cost of paving is also important: in case 3 (no growth in traffic but a 50 percent increase in cost), the optimal traffic threshold for paving jumps from 270 vehicles a day to 425. But the penalty for not paving at the optimal traffic level is not large, and considerations other than traffic may govern the choice.

One consideration is whether future maintenance is likely be done to acceptable standards, on both paved and unpaved roads. If, on the one hand, the availability of future maintenance funds is uncertain, the best policy is to defer paving. The present value of the total life-cycle transport costs associated with a gravel road (even if suboptimally maintained) will be less than that for a paved road if adequate funds may not be available when the paved road begins to deteriorate sharply. If, on the other hand, the country's ability to plan and execute maintenance is in doubt, early paving (and therefore fewer roads) is indicated. The present value of the total life-cycle transport costs associated with an unmaintained gravel road will exceed that of an unmaintained paved road down to the point at which the roads cease to be serviceable. These conclusions, which have been stated in the broadest terms, reflect the joint effect of discounting and the nonlinear path of deterioration of paved (but not unpaved) roads (see appendix B).

Figure 2-3. Break-even Traffic Volumes for Paving a Gravel Road



Note: Case 1 (the base case) assumes no growth in traffic and optimal maintenance policies on paved and unpaved roads; case 2 assumes a traffic growth rate of 6 percent a year and the same maintenance policies as in case 1; case 3 assumes no growth in traffic and a 50 percent increase in paving costs.

Strong or Weak Pavements

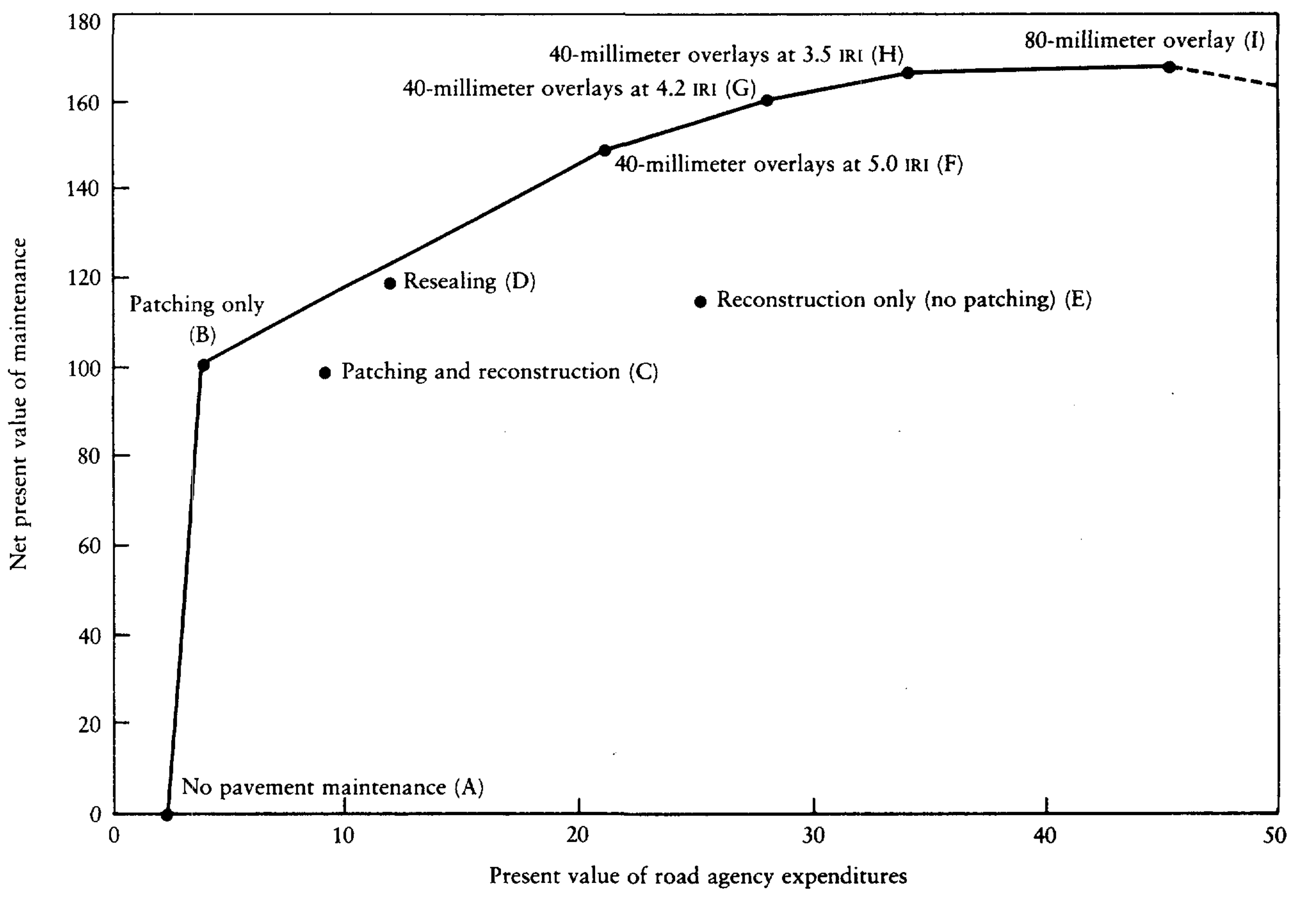
An important question in determining the paving strategy is whether it makes economic sense to begin with a low-strength design and then strengthen the pavement later to accommodate heavier traffic and axle loadings. The answer depends on the quality of maintenance that can be expected on the (initially) lower-strength road. The question was explored for conditions in Costa Rica and Mali. The studies, which assumed a 3 to 4 percent annual growth in traffic and two levels of axle loads, indicated that with a 75 to 90 percent probability of adequate maintenance, staged construction would be economical for initial traffic flows of up to 2,000 or 2,500 vehicles a day, depending on axle loads. But with only a 30 percent probability of adequate maintenance, strong pavements should be built initially, despite the higher construction cost, to compensate for unreliable maintenance; in this case staged construction would be the preferred alternative only at traffic volumes of less than 1,000 vehicles a day with light axle loads. In all cases the pavement should conform to minimum design and construction specifications. A technical option that has not been sufficiently explored in developing countries, particularly in the humid tropics, is the use of pavements made of portland cement. Although they are costly to construct, concrete pavements can provide an initial service period of fifteen to twenty years that is nearly maintenance free.

Some countries made expensive mistakes by staging the construction of pavements under assumptions of adequate maintenance and restricted axle loads that proved invalid. Heavy loads accelerate road deterioration, and even with optimal maintenance the average life-cycle roughness remains higher with heavier axle loads. Empirical evidence shows that pavement damage increases exponentially (to the power of 4) with increased axle loads. But the regulation of axle loads has proved exceedingly difficult and expensive. Many road authorities are now building stronger, more expensive pavements than would be necessary if axle loads were effectively controlled. Even if load regulations could be enforced, the limits should be increased beyond the prevailing eight- to ten-ton single (and thirteen- to sixteen-ton tandem) axle loads, because the economic gain from the use of larger trucks outweighs the increased damage to roads (Faiz and Fossberg 1987; Rolt 1981).

Tactics under Budgetary Constraints

Road authorities frequently do not have enough funds for the economically optimal level of maintenance. When budgets are constrained, the best policy is not simply to reduce all categories of maintenance spending equally, as is often done. The situation calls for revising policies and using different maintenance options. The management of retrenchment (and, in

Figure 2-4. Net Present Value versus Road Agency Expenditures for Alternative Maintenance Strategies for a Paved Road in Fair Condition
(thousands of dollars per kilometer)



Note: Average daily traffic = 800 vehicles. See appendix B for specifications of the maintenance alternatives represented by each point on the graph. It is possible to operate on the frontier between two of the points by using one policy on some roads and the other policy on others. For example, a combination of policies F and G could use funds equal to those required for policy E and achieve a net present value on the frontier. Thus policy E is inferior and should never be used. Similarly, any other points below the efficiency frontier represent policies that should not be used. In the case illustrated, policy D (resealing) is inferior to a strategy combining the B (patching only) and F (overlay) options. In other cases, resealing will often turn out to be an efficient way to prolong the functional life of pavements. The relative position of various policies will change significantly with changes in the discount rate and the relative cost of different maintenance alternatives.

extreme cases, network contraction) has not yet been thoroughly analyzed, but some measures have been found to be effective in controlling the retrenchment process and preventing it from becoming haphazard.

Typically, when spending priorities are established the tradeoffs between road agency costs and the net benefits of different maintenance strategies are not examined. As long as the net present value of a maintenance option is positive, it is deemed justifiable—whatever the cost to the agency. But if the analysis is extended to road agency expenditures, there appears a big margin for reducing them without making large cuts in the benefits to road users. Figure 2-4 shows the net present value of alternative maintenance options applied to a specific class of roads. The line connecting the points that are highest in net present value for given agency expenditures is the efficiency frontier. The optimal strategy, if unlimited funds and a discount rate of 12 percent are assumed, would be that shown at point I. In addition to basic routine maintenance, this strategy requires the immediate application of an 80-millimeter overlay, to be followed by 40-millimeter overlays whenever roughness exceeds 3.5 IRI.

The efficiency frontier is rather flat immediately to the left of the optimum point; alternatives in this zone can significantly reduce agency costs with only a small impact on total transport costs. As agency expenditures are cut back, vehicle operating costs increase, but by only a little more than the savings in maintenance expenditures. Moreover, the tradeoffs in the vicinity of the optimum do not imply higher future costs for road rehabilitation. It is simply a matter of maintaining the roads at a somewhat rougher level, with a consequent saving to the road agency and somewhat higher costs to road users. In general, such tradeoffs were found in the vicinity of the optimal strategy in most of the other cases studied.

But as the budget departs further from the optimum and maintenance is cut back correspondingly, vehicle operating costs increase by much more than the savings to the road agency. In addition, the changes in maintenance policy entail increasingly greater risks of pavement failure, which means much higher costs for reconstruction in the future. In summary, the range of good maintenance policies is wide, but below a certain level of funding the consequences of further reduction become destructive.

Sometimes a government must take austere measures to deal with a national emergency or adjust to economic conditions. It may cut back budgets for a year or several years, with the intention of restoring them to normal levels later. In such circumstances road maintenance is often deferred. If roads are in good condition, the deferral may not be too costly. Increased roughness caused by undermaintenance will increase vehicle operating costs somewhat, but roads that decline to fair condition can be restored with a modest additional expenditure. If the deferral continues too long, however, or if roads are in only fair condition to begin with, the impact on vehicle operating costs will be greater. And paved roads that decline to poor condition will require far more expensive reconstruction later on. That is why road agencies should take deliberate account of the risk of future budget interruptions when making choices about road design and maintenance. Good maintenance in normal times is one way to minimize the impact of future interruptions in funding.

3

The Institutional Challenge

Choosing the best maintenance policy will remain an academic exercise until institutions can efficiently put the policy into practice. Past experience is not encouraging. The World Bank advanced more than $1.2 billion between 1971 and 1985 for training, technical assistance, and management consultancies to improve the organization and management of road administration in developing countries. Other lenders and donors and the developing countries have also devoted substantial resources to this purpose. Despite these efforts to improve operational and administrative performance, it has been difficult to establish self-sustaining institutions that can manage road maintenance efficiently or use external resources effectively.

Experience has provided no standard solutions to the problems of institutional performance. Without proven formulas, institutional development has had to proceed by continuous, local experimentation. Experience has, however, identified constraints on improved performance and some general principles worth pursuing (Harral 1987).

The Constraints

Three factors have worked against the development of effective institutions for road maintenance:

- The nature and constitution of the typical road agency. Most road authorities have conflicting objectives and functions and therefore operate under incompatible incentives.
- The weak public pressure for better roads.
- The inadequacy and unreliability of funding.

Structure and Functions of the Road Agency

World Bank efforts to improve the management and maintenance of roads have focused on road authorities, which typically operate as public sector monopolies. These agencies are generally responsible for three functions: (a) planning the development and maintenance of roads, (b) negotiating with, and overseeing the work of, contractors, and (c) constructing and maintaining roads using their own work forces (force account). The division of work between contractors and force account varies by country. For the most part, however, contractors undertake new construction and large rehabilitation projects, and the road agencies take care of routine maintenance themselves. Resurfacing operations are sometimes shared, sometimes not. In some countries contractors also do routine maintenance, and in others the agency's work force also constructs new roads.

Contracted works for new construction and rehabilitation normally constitute the greatest part of an agency's expenditures. But direct execution of maintenance accounts for the largest share of road authority employment and for a disproportionate share of difficulties.

Conflicts may arise when a state organization combines the planning and control of construction and maintenance operations with the direct execution of works. Internal control is blunted and efficiency prejudiced when direct execution receives too much emphasis, if only because of the political significance of the large labor force employed. Already weak incentives for efficiency are undermined by the constraints of public service. Civil service rules circumscribe managerial decisions. Deficient salary scales and promotion systems make it difficult to retain competent staff. Employment objectives frequently smother the technical work of the authority and distort its decisions (box 3-1).

Weak Public Pressure

Because road agencies do not operate transport services, they do not suffer directly from bad maintenance. Nor do they normally sell services to road users in a competitive market. They thus do not bear the full cost of neglected maintenance; nor are they subject to market pressure, as railways are. Also absent is the pressure from direct dealings with the public—pressure felt by public health, education, and transport services, for example. Truckers rarely experience enough competition from other transport modes to complain about the high cost of operating vehicles on bad roads, and car owners and businesses are too dispersed to form effective pressure groups for better roads. Furthermore, the effects of neglecting maintenance are unlikely to be perceived before the problem has become acute. Without pressure groups to prod them, politicians and administrators have little concern for the roads, and the road agency becomes a facility for political patronage and unemployment relief.

Inadequate Budgets

Lacking political support and shielded from market pressures, the budgets for road maintenance are often unrelated to known requirements. Because much of the budget goes toward the wages of an unnecessarily large labor force, the disposable portion fluctuates much more than the total when budgets are cut or prices rise. A small cut can bring much of the agency's work to a standstill if, for example, it means the agency cannot buy fuel or spare parts. Moreover, even when funds have been appropriated for maintenance, political or private interests put pressure on road authorities (or their financial sources) to divert funds to other purposes. Such interference, often one of management's biggest challenges, can be controlled only in the political arena.

The Search for Solutions

Efforts to improve the efficiency of institutions for road management must focus on ways to make these institutions accountable for their performance.

Internal Accountability

The absence of internal accountability is a common cause of the institutional failure of road agencies. Planning, supervision, and execution are normally combined in the same organization. Road agencies seldom link the allocation of funds to explicit physical plans and rarely perform postproject evaluations. To improve accountability, planning and supervision must be separated from the execution of works, and procedures must be introduced to ensure that the projects are evaluated. One way of doing this is for the road agency to award maintenance contracts through competitive bidding and then to supervise and evaluate the work closely. Raising the visibility of maintenance objectives and performance is equally important. Unless this is achieved, the chronic

Box 3-1. Overstaffing and Resource Imbalances in Kenya

The effects of the general budgetary squeeze on operating funds (for fuel, spare parts, and bitumen, for example) have been exacerbated in Kenya by two parallel developments affecting the Roads Department. One is the decision to integrate casual labor with the permanent work force; the other is the implementation of the District Focus Program, a broadly based effort to decentralize government functions. Until 1982 the (central) Roads Department employed an average of 1,000 permanent staff and about 9,500 casual workers. Wages and emoluments amounted to 134 million Kenyan shillings (K Sh), and operating funds totaled K Sh194 million, which was already inadequate.

Three years later, however, the situation had deteriorated dramatically because of increases in the size of the permanent work force and decentralization of the road agency's functions. The Roads Department's casual workers (and some personnel from other departments) had been integrated with the permanent work force at the district level, and the number of personnel had risen to 14,600. More than 90 percent of the K Sh210 million allocated from the central budget to the districts went for personnel-related items, which left little for operating expenses. Meanwhile, funds for operations that were centrally controlled (including most equipment-based operations) were down to K Sh126 million.

underfunding of maintenance in developing countries will be difficult to reverse.

Also essential for an agency's accountability is monitoring by an independent authority. Performance audits should relate financial flows and physical performance indicators to the state of the roads. A system for collecting the data needed to monitor performance is therefore equally necessary. The data can also be used to make an independent and public assessment of the agency's performance. In the United Kingdom, for example, county road authorities have to publish annual reports that show their costs in comparison with private contractors' charges (Cox 1987).

Public Awareness

Greater public awareness, including that of potential interest groups (contractors, exporters, transport enterprises), is important for shaping policy and mobilizing support for programs to restore and maintain roads. The Swedish National Road Administration, for example, conducts periodic surveys (using questionnaires) to find out what the public thinks about its work. It uses the results to redirect its policies and operations and to persuade Parliament and the government to keep highway funding at adequate levels. The public information programs of professional societies and trade associations—such as the American Society of Civil Engineers, the American Automobile Association, and the National Asphalt Association—have helped to arouse public concern about the state of roads in the United States (Choate 1983). Performing a similar role in France, the national and regional associations of contractors (Fédération Nationale des Travaux Publics and Fédération Régionales des Travaux Publics) lobby for increased public spending on roads. In Japan, the Road Association, an interprofessional body with private and public representation, promotes public interest, both technical and general, in the condition of the country's roads and acts as an effective lobby at all levels of government.

Elements of Reform

Management systems that work in developed countries have not always improved the operation of road maintenance institutions in developing countries. Reforms will thus have to be experimental (Harral 1987; Faiz and Bennathan 1988).

Decentralization or Functional Separation

Decentralizing the organizations for road maintenance has often been advocated as a first step in reform. Decentralization is seen as a way to make the road authority more responsive to local needs and to reduce the difficulties of managing activities that are geographically dispersed. An argument against decentralization is the fear that technical and managerial staff would be spread thin or that maintenance funds would be diverted to more politically popular (or more conspicuous) but less worthwhile construction activities. Decentralization could also lead to the employment of excessive local staff—as in Kenya and Honduras. The Bank's experience is not conclusive on these points and finds little correlation between success in road maintenance and the degree of centralization. Thus case-by-case experimentation seems the only practical prescription.

More obvious is the need to separate the execution of works from the planning and control functions, for this would help to insulate planning and control from the pressures of operating a works program. If execution were turned over to private contractors, the road agencies would be freer to concentrate on procuring and managing resources. Private contractors operating under the incentives of a competitive environment offer better prospects for developing an efficient, lasting institutional capacity for carrying out road maintenance services. They can also constitute an informed group with a direct interest in the adequacy of road maintenance budgets. Moreover, experience suggests that private competitive organizations use and maintain machinery more effectively than do government agencies (box 3-2) and can perform work at lower cost.

A review of experience with the contracting of maintenance in nine countries found that roads under contract were generally well maintained in seven of them—Argentina, Brazil, Central African Republic, Ghana, Kenya, the United Kingdom, and Yugoslavia (Harral, Henriod, and Graziano 1986). The problems encountered in initial experiments in the other two (Colombia and Nigeria) are being evaluated. By and large, contract maintenance tends to be more cost-effective than maintenance by direct labor, and contractors have been attracted to maintenance opportunities, even in remote areas. In many cases small local contractors can operate in such areas more cheaply than the central road administration or larger contractors.

The desirability of contracting a major part of routine maintenance and resurfacing operations deserves wide consideration. A small government maintenance capacity can be retained to ease the transition, provide backup for emergencies, and reduce the risk of replacing a public monopoly with a cartel of private interests (as occurred in Nigeria and

Box 3-2. Underutilization of Equipment in Western Africa and Latin America

Road maintenance surveys by the World Bank in 1985 found that vehicles and equipment were seriously underutilized in Western Africa and Latin America. Utilization rates in these two regions were far below the 1,250 hours of operation a year that is generally regarded as efficient. In Western Africa the average annual hours of operation ranged from 420 for rollers to 840 for dump trucks. In Latin America utilization averaged 750 hours for equipment and 800 for vehicles; crushing plants were utilized even less, and asphalt finishers had the lowest rate—420 hours a year.

In Western Africa the primary cause seems to have been a shortage of spare parts and fuel. About 40 percent of the road authorities received only half the funds needed to purchase enough spare parts to keep their fleets fully operational. Fuel expenditures in nine countries in 1982 were only about one-third the amount needed for 1,000 hours of operation. The lack of spare parts hindered maintenance, and the shortage of fuel restricted operation.

Low utilization is harder to explain in Latin America. With three exceptions, the road authorities surveyed were able to purchase enough spare parts to operate the fleets 1,000 hours a year. About 40 percent of the agencies had less than two-thirds of the funds needed for fuel for 1,000 hours of operation a year. But the rest did sufficiently better to raise the regional average to 82 percent of the funds needed for fuel. Poor equipment management and, possibly, a shortage of qualified operators and mechanics may partly explain the low rates of utilization.

to a lesser extent in Brazil). Japan's policy of relying on contract maintenance is reinforced by numerical limits on the labor force that government agencies may hire. An increase in the demand for civil works leads automatically to the use of contractors. Even the field offices of the local public works administrations can let maintenance contracts of a limited, but far from negligible, value. Publicly owned equipment is kept at minimal levels, just enough to meet emergencies, so that the investment in government-owned workshops and inventories of spare parts is very small. The United Kingdom has had promising initial results with a program (begun in 1981) that requires the agency's work force to compete with private contractors (Cox 1987). In this way both sides are encouraged to be efficient and to assemble reliable cost data.

Contracting Techniques and Skills

The use of contractors can reduce the burden on the road authority, but it increases the need for supervisory management. Harnessing the profit motive to get the work done well, on time, and at reasonable cost requires knowledge of contract design. The contract should not provide uneconomic incentives (as in a cost-plus contract) or restrict the contractor's freedom to seek cost-saving methods and sources of supply. Where institutional capability is limited, outside management consultants and specialists can help to develop management systems and contract instruments—as well as provide training for government staff and contractors.

If well-established domestic contractors are not available, the trial introduction of small contracts (say, for routine maintenance that is technically simple and requires little investment) can reduce risks and help develop the capabilities of government and contract personnel. All successful contracting schemes have involved close coordination between the government and contractors in defining and planning the work. Such schemes have also changed the role, sources, and contractual modes of foreign technical assistance.

Human Resources

Better use can be made of human resources in several facets of road maintenance. Unskilled labor can be substituted for machinery—a cost-effective solution when wages are low, activities are properly organized and managed, and suitable incentives are built into the system (Coukis and others 1983). And many countries have had good results with the simple "lengthman" system. Under this system people living alongside a road are responsible for maintaining it, and their payment and continuing employment are contingent on satisfactory performance.

Low and inflexible civil service salary scales make it difficult for government agencies to retain competent managers, engineers, technicians, foremen, mechanics, and others with special skills. Sometimes incentives can help an agency hold on to its most productive staff. The road authority in Ethiopia, after some trial and error, devised a bonus scheme based on work-unit productivity. Agencies in several other countries use special allowances to encourage field supervision by middle-level managers. But despite these and similar schemes, staff turnover is likely to continue to be high. Road authorities may as well recognize their usefulness as a training and proving ground for personnel who will move on to the private sector.

Personnel management—or mismanagement—is the area with the most potential for improvement. Staff must be motivated and inculcated with a sense of duty and accountability; good performance must be recognized and rewarded. Recruitment and appointment to senior positions should be based on competence, not patronage, seniority, or other antiquated civil service regulations and policies. Weak performance stems not from inadequate training—on which it is all too often blamed—but rather from inadequate, nonexistent, or unenforced personnel management policies. Although its importance cannot be emphasized enough, training must be an integral part of personnel management. Since the work of road maintenance is dispersed throughout a country, an effective and fairly low-cost way to train maintenance staff is through road extension services modeled on the training and visit system used in agriculture (Benor, Harrison, and Baxter 1984; Transportation Research Board 1986).

Technical Assistance

Technical assistance for road maintenance has traditionally been concentrated on advisory services, management systems, and training for road authority personnel. Technical assistance personnel usually act as advisers and rarely take part in line operations. As a result, providers of technical services have little exposure to risk, few incentives for improving performance, and only indirect responsibility (if any) for measurable output. Among the exceptions are the technical assistance programs of Australia, France, and the United Kingdom, which have provided technical staff for senior line positions in the highway agencies of such countries as Côte d'Ivoire, Djibouti, The Gambia, Malawi, Niger, and Papua New Guinea. The effectiveness of such assistance is greatly enhanced if the technical ministries of the sponsoring countries provide adequate backstopping.

Some schemes have tried to establish performance incentives for suppliers of technical assistance by redefining their role and leaving them more of the risk. But the traditional suppliers cannot generally afford to take significant risks. So it may be desirable to look for new sources of assistance, such as international civil engineering contractors. These companies are accustomed to risk-taking ventures and performance-related incentives. Their staff have the requisite qualifications and are used to working as management teams in developing countries.

Another option is a "twinning" arrangement between a developing country's road agency and a partner institution in a more developed country. Such arrangements can facilitate regular exchanges of middle-level managers and technical staff. They can also provide for the transfer of technology,

Box 3-3. Twinning of Turkish and U.S. Highway Organizations

In 1947 the United States initiated a program to help Turkey develop a highway organization capable of constructing and maintaining an expanding road system (U.S. Department of Transportation 1976). The U.S. Public Roads Administration (PRA) was entrusted with this task. During the first phase of the program the PRA made an assessment of highway development in Turkey and concluded a formal agreement with the Turkish government on the objectives of the program and arrangements for its implementation.

PRA staff initially provided the core organization for the work. Specialists were added as required, but as soon as Turkish personnel could take over an organizational unit, that unit was dropped from the technical assistance program. The first division to be transferred to exclusive Turkish administration was the Planning and Programming Division.

When the technical cooperation program began in Turkey, local counterparts could not be found for many of the positions in the technical divisions, such as Materials or Survey and Design. To fill this gap, training programs were organized, and the better graduates went on to become instructors for new classes. The Turkish personnel gained practical experience as they built and maintained the highway system, and when recruiting satisfactory equipment operators proved difficult, the Turkish Army supplied men and officers for the program.

The last U.S. adviser left Turkey in 1958. By then the Turkish General Directorate of Highways had evolved into a first-class organization capable of maintaining 27,000 miles of all-weather national and provincial highways, most of which were improved or constructed during the period of U.S technical cooperation.

procedures, and information systems (Cooper 1984). The Federal Highway Administration of the United States has collaborated in such arrangements with the highway authorities of Argentina, Ethiopia, Jordan, Liberia, Nepal, Philippines, and Turkey, among others (see box 3-3) (U.S. Department of Transportation 1976). France, through its technical services agencies, has provided similar assistance to road institutions in Algeria, Cameroon, and Côte d'Ivoire. Equally important are technical cooperation and exchange programs between developing countries. These permit the transfer of appropriate technology and cost-effective management systems and allow countries to share their experiences with institutional reform. The road maintenance conferences organized by the regional U.N. agencies (the Economic Commission for Africa, the Economic Commission for Latin America and the Caribbean, and the Economic and Social Commission for Asia and the Pacific) have played an important role in fostering the exchange of road maintenance experience among developing countries.

4

Financial Requirements

Few developing countries have spent wisely, or enough, on road maintenance. Not all roads have to be kept in the best condition to maximize economic returns, but heavily used roads should not be allowed to deteriorate—especially when a fairly small, properly timed expenditure for maintenance would make reconstruction unnecessary. The costs for restoring deteriorated and rapidly deteriorating roads are substantially more than most developing countries have been spending. But far greater sums are at stake if the situation is not handled better over the next decade.

The Overall Picture

The financial requirements of the road deterioration problem have two parts. One is the cost to restore (rehabilitate or reconstruct) those roads that are in poor condition and warrant saving. The other is the future annual cost of maintaining the whole network at economically warranted standards (Smith and Harral 1987).

The Cost of Restoration

The total cost to restore the backlog of degraded main roads that warrant saving in the eighty-five developing countries is about $43 billion (table 4-1). Even without a claim to accuracy, this number provides an order of magnitude. Bridges and large tertiary and lower-order networks are not included, but a speculative estimate for such components is about $15 billion to $25 billion. Under the constraints of limited budgets, only some of these components would qualify as economically warranted. The estimate also excludes about $3 billion for partial rehabilitation of low-volume main roads in the poorest countries of Sub-Saharan Africa. Full restoration of these roads would not be economically warranted, but they should be maintained to higher standards than they are now.

Future Costs

Strongly affecting future costs will be the money spent (and effectively used) in the next few years to prevent more roads from deteriorating into poor condition. A high proportion of the paved network (more than 40 percent in 1984) is or will soon be in only fair condition and will therefore require extensive maintenance to prevent structural failure. It is estimated that resurfacing and routine maintenance needs will amount to about $4.7 billion a year (table 4-2) over the next few years. If these needs are not met in time, however, the costs will multiply rapidly. An example of inadequate spending is the $43 billion worth of restoration needed now because some $12 billion of preventive maintenance was neglected over the course of a decade or so.

Required Allocations

The funds needed to prevent further deterioration and to clear the $43 billion backlog of rehabilitation

Table 4-1. Total Expenditures Required to Meet the Estimated Restoration Backlog in 1984
(billions of dollars in 1986 prices)

Region	Rehabilitation and reconstruction: Paved roads	Rehabilitation and reconstruction: Unpaved roads	Total	Total as a percentage of GNP: Median	Total as a percentage of GNP: Range
Eastern and Southern Africa	1.4	0.8	2.2	3.3	0.0–15.5
Western Africa	1.9	0.9	2.8	3.2	1.2–36.9
East Asia and Pacific	7.5	1.8	9.3	1.6	0.2–2.5
South Asia	7.7	0.9	8.6	3.5	2.5–12.7
Europe, the Middle East, and North Africa	8.4	0.9	9.3	2.6	0.4–7.4
Latin America and the Caribbean	7.9	3.1	11.0	2.0	0.4–22.8
Total	34.8	8.4	43.2	—	—
Percentage of total	81	19	100	—	—

— Not applicable.
Note: The estimation procedures are described by Smith and Harral (1987). A few countries in each region account for a large proportion of the region's restoration needs—Eastern Africa: Madagascar + Zambia = 40 percent; Western Africa: Nigeria + Ghana = 58 percent; East Asia and Pacific: China = 56 percent; South Asia: India = 64 percent; Europe, the Middle East, and North Africa: Turkey + Yugoslavia + Algeria = 56 percent; Latin America and the Caribbean: Brazil + Argentina = 63 percent.

Table 4-2. Annual Maintenance Expenditures Required to Prevent Deterioration, 1986–90
(billions of dollars in 1986 prices)

Region	Routine maintenance	Resurfacing: Paved roads	Resurfacing: Unpaved roads	Total	Total as a percentage of GNP: Median	Total as a percentage of GNP: Range
Eastern and Southern Africa	0.2	0.1	0.1	0.4	0.7	0.2–1.8
Western Africa	0.1	0.1	0.1	0.3	1.0	0.1–3.5
East Asia and Pacific	0.3	0.8	0.2	1.3	0.2	0.1–0.4
South Asia	0.1	0.3	0.1	0.5	0.3	0.2–1.1
Europe, the Middle East, and North Africa	0.2	0.5	0.1	0.8	0.3	0.1–0.6
Latin America and the Caribbean	0.5	0.6	0.3	1.4	0.4	0.1–2.8
Total	1.4	2.4	0.9	4.7	—	—
Percentage of total	30	51	19	100	—	—

—Not applicable.

needs (in either five or ten years) are summarized in table 4-3. If all countries were to meet the five-year target, the cost, reckoned without discounting, would be about $13 billion a year ($4.8 billion for maintenance and $8.6 billion for restoration). For the ten-year target the cost would be about $9 billion a year ($4.8 billion for maintenance and $4.3 billion for restoration). The foreign exchange requirements would be $6 billion for the five-year target and $4 billion for the ten-year target.

These estimates are less than economically optimal because they emphasize holding down road agency costs at the expense of higher costs to the users (especially in the ten-year program). This emphasis gives priority to saving roads in fair condition to minimize future restoration costs, even if the social return from reconstructing heavily traveled roads in poor condition would be greater because of the savings in vehicle operating costs.

Costs could be reduced by improving the productivity of maintenance, but it is not clear whether such gains are attainable in the short run. Although there is scope for improvement in the areas of labor, equipment, and procurement and supply, such gains are likely to be disrupted if the institutional structure is defective. Even when supported by an infusion of technical assistance, such gains are difficult to sustain without the commitment and dedication of local staff and managers of road authorities. Productivity gains are likely, therefore, to account for only a small reduction in the short-term bill.

Total road expenditures, including those for new construction, in the eighty-five countries are estimated at $10 billion to $13 billion for 1984, and restora-

Table 4-3. Annual Financing Requirements for Restoration and Maintenance of Roads
(billions of dollars in 1986 prices)

Region	Total cost		Foreign exchange	
	Ten-year target	*Five-year target*	*Ten-year target*	*Five-year target*
Eastern and Southern Africa	0.6	0.8	0.3	0.4
Western Africa	0.6	0.9	0.3	0.5
East Asia and Pacific	2.2	3.1	0.9	1.3
South Asia	1.4	2.3	0.6	0.9
Europe, the Middle East, and North Africa	1.8	2.7	0.8	1.3
Latin America and the Caribbean	2.5	3.6	1.2	1.7
Total	9.1	13.4	4.1	6.1

tion and maintenance may have accounted for about 50 percent of this. With $4.8 billion a year required for future maintenance, little would be left for catching up on the rehabilitation backlog. In many countries the restoration and maintenance budget is too small to stabilize the road networks in their present condition, let alone rehabilitate them.

Country Differences

Countries differ widely in their financial requirements for road maintenance and restoration, their ability to marshal and allocate the needed resources, and their capacity to use additional resources effectively.

Financial Constraints

The financial severity of a country's road restoration requirements can be gauged in two ways. One is to estimate how much the current funding for maintenance could be increased by reallocating funds within the overall budget for the sector. The other is to look at the rate of growth of real GNP per capita during the period 1975–85. The first criterion shows what could be done with current road funds. The second gives a crude indication of the potential for increasing those funds. Although any indicator of the potential for increasing funds is open to question, the growth of real GNP per capita is believed to be a valid indicator for most countries. (There are bound to be exceptions: the oil-producing countries and others linked to them economically had unusually high growth rates during 1975–85 but are now facing adjustment problems because of the recent drop in oil prices.)

Current road budgets (based on funding from domestic sources and, in some cases, external assistance) were placed in three broad categories according to their adequacy for restoration of the road network:

- *Sufficient financing capacity.* Current road funding, if reallocated, would be sufficient for adequate maintenance of the network, complete restoration within five years, and new construction amounting to at least 20 percent of the total.
- *Moderate to marginal financing capacity.* Current funding would have to be increased by up to 50 percent and new construction held to 20 percent of the new total to ensure adequate maintenance and complete the restoration in ten years. (Although there is a wide definitional gap between this and the preceding category, none of the countries fell within that gap; thus there is a clear distinction between the two groups.)
- *Insufficient financing capacity.* Even if current funding were increased by 50 percent and new construction held to 20 percent of the new total, funds would be insufficient to complete the restoration in ten years.

These criteria were applied to the sixty-one countries for which expenditure data are available (see table 4-4). More than half the countries with insufficient budgets to finance their road requirements (eleven of sixteen) had negative rates of real GNP growth. Of these, nine are in Sub-Saharan Africa, where extensive road building and paving in recent decades set the stage for today's rapidly worsening maintenance situation. These countries have the greatest need to increase their road budgets and the poorest prospects of doing so. They represent the hard core of the road maintenance problem in the developing world.

A somewhat different problem affects China and several countries in South Asia (Bangladesh, Burma, India, and Pakistan). In general, many of their roads were built long ago to standards of strength and geometry that are totally inappropriate for today's

Table 4-4. Road Restoration and Maintenance: Financing Capacity in Sixty-one Developing Countries

Annual growth of real gross national product per capita, 1975–85	*Capacity to finance restoration and maintenance*[a]		
	Sufficient	*Marginal*	*Insufficient*
Over 2.5 percent	*Rep. of Korea *Yemen Arab Rep. *Cameroon *Lesotho *Indonesia	*Botswana Arab Rep. of Egypt *Paraguay *Thailand Tunisia Algeria Yugoslavia	*People's Dem. Rep. of Yemen Burma Pakistan Sri Lanka
0–2.5 percent	Hungary *Colombia Turkey *Rwanda *Burundi *Oman *Nepal Honduras Ecuador *Malawi Philippines Dominican Rep.	India Morocco Brazil Chile Portugal *Burkina Faso *Benin *Kenya Mali Guinea	Bangladesh
Negative growth	*Papua New Guinea *Niger *Côte d'Ivoire *Nigeria	*Swaziland *Costa Rica Uruguay Zimbabwe *Central African Rep. *Togo Argentina	Sierra Leone *Mauritania Zambia Tanzania *Senegal Madagascar *Gambia *Liberia Zaire Jamaica Bolivia

Notes: Countries are listed in descending order of annual rate of growth of real GNP per capita for 1975–85. Countries with recently expanded or improved networks are marked with an asterisk.

a. The capacity to finance is based on the national highway budgets (1981–85), which include, in certain cases, external borrowings or grants. The assessment of financial capacity is somewhat subjective because highway budgets fluctuate significantly over time in many countries. This classification therefore may not accurately represent developments after 1985.

traffic. Although these roads, too, have deteriorated extensively, many of them should not be rehabilitated. Instead, they should be replaced by roads of a capacity adequate for present and expected requirements.

Reallocation of Funds

Aside from the countries with obsolete networks that need to be replaced, almost all the countries listed in table 4-4 will have to reallocate funds from new construction to rehabilitation and maintenance if they cannot increase their road budgets significantly. For many, the reallocations will have to be drastic. Even countries with "sufficient" financing capacity will have to shift funds from one category to another, and this is difficult to do in many countries because of the budgeting process. Some countries have separate national budgets for capital and current expenditures, with construction in one and rehabilitation and maintenance in the other. In many countries road construction is part of the general development plan and is controlled by a special office or ministry separate from the ministry or bureau responsible for maintenance. In such a system it is almost impossible to reallocate road funds from construction to rehabilitation and maintenance once the budget has been drawn up. (A change in allocations would require a top-level decision before budgets are submitted, and such a decision would probably encounter strong resistance from the entity whose construction funds were to be reduced.)

Reclassifying the budget could ease the consequences of separating construction from rehabilitation and maintenance. For example, resurfacing and rehabilitation of worn-out roads could reasonably be classed as capital rather than recurrent expenditures. Capital project planners might then pay more attention to the need to maintain older roads and to assess the future maintenance requirements of new construction projects. The budgetary constraints on rehabilitation would also be less rigid. Such a reclassification should also be useful in reorienting the programs of external aid agencies. Another possibility would be to integrate capital and current budgets and to select maintenance, rehabilitation, and new construction projects on the basis of their economic worth—taking into account future streams of maintenance requirements and road user savings in each case.

Absorptive Capacity

Money is not enough, because expanding the capacity to use funds effectively can be very difficult. Most of the countries considered will have to expand their rehabilitation and maintenance operations, whether by shifting resources from construction or by other means. Road maintenance agencies will have to handle maintenance efficiently and on a much larger scale than before. All this is likely to require a tremendous expansion of the maintenance capabilities of the government or private contracting firms, or both. Machinery will have to be acquired, and operators and mechanics will have to be trained. Above all, the managers and staff of the road agency will have to learn how to plan, manage, and supervise maintenance work efficiently on a large scale.

Expansion may be especially troublesome for countries with recently expanded networks of paved roads. Many of these countries have had little experience with maintenance and are ill prepared to carry out the timely maintenance activities that will prevent the need for far more expensive rehabilitation. Slightly more than half of the thirty countries in table 4-4 with new paved networks are judged to have problems with their absorptive capacity. Although such judgments, which are based on Bank experience, may be subjective, the overall balance is realistic. Some Sub-Saharan countries with relatively new networks are afflicted by the worst combination of problems: insufficient financial capacity, negative growth rates, and problematic institutional capacity.

Marshaling Domestic Resources

Funds reallocated from new construction and gains in efficiency will seldom be sufficient to finance the swelling costs of restoration and maintenance. A common method for increasing revenues to finance road expenditures is to raise road user taxes and other charges. Taxes on vehicles and supplies are often a convenient source of general revenue in countries where the capacity to tax final products or incomes is limited. But high road user taxes may distort transport costs and lead to economically inefficient business decisions about location, production, and investment. When distortions exist, taxes should be raised only after their structure is adjusted to reduce distortions. For example, where heavy vehicles pay less than the cost of the damage they inflict on roads, a tax increase should be structured not only to raise more revenue but also to encourage the use of multiple axles to reduce road damage. To the extent that additional levies on road users are translated into better roads, they will reduce (not increase) road user costs.

Practically all the arguments of fiscal economics go against earmarking taxes for specific purposes such as road maintenance. Nevertheless, earmarking is used in a variety of developing and developed countries and should not be ruled out from consideration in two cases. Where fiscal control is weak and revenue allocation and disbursement are subject to seepage or long delay, earmarking can ensure that the government's decision to maintain and rehabilitate roads is translated into practice. Short-circuiting the budget may then make for a more rational use of resources. In the second case—where a special tax is to be levied (or a rate raised) to finance road rehabilitation—the principles of benefit taxation apply. Here the taxpayers know what they should expect to get in return. Such a targeted tax should have a limited duration.

In either case, earmarking can be recommended only if the fiscal integrity of the receiving authority (say, a road fund) and its determination to apply the funds according to economic priorities are ensured. A frequent problem is that money earmarked for the road fund does not find its way there or is used inefficiently or for purposes other than maintenance. One of the few reasonably successful schemes in developing countries emerged only after much trial and error in the Central African Republic (see box 4-1).

External Financing and Assistance

The sheer size of the task now facing many developing countries implies massive demands for external financing. The foreign exchange components of the financing requirements range from 30 percent for routine maintenance in middle-income countries to 70 percent for restoration of paved roads in low-income countries. In many cases external financing will have to cover more than the foreign exchange component to preserve the infrastructure. In the group of countries at the hard core of the problem, no solution is conceivable without external financing.

External financing will have to be concentrated on restoration and maintenance if the countries' efforts are not to be diverted to lower priority investments (Faiz and others 1987). The World Bank has progressively sharpened the focus of its lending for highways. From 1975 to 1985, 53 percent of the Bank's lending for highways ($5.0 billion of $9.4 billion) was for rehabilitation, maintenance, and technical assistance largely related to maintenance. Some multilateral and bilateral agencies, particularly those with a longer history of providing assistance for highway development, also raised the share of maintenance and rehabilitation in their financing of roads. But from 1981 to 1984 most of them continued to provide assistance for new construction, even to countries with mounting maintenance backlogs. Bilateral aid tended to have a higher proportion of new construction and improvement works than did multilateral assistance (table 4-5).

In general, it makes sense to use external finance primarily to increase a country's capital assets and domestic finance to cover current costs, such as those for maintenance. (This is the tendency in most countries in East Asia and in Europe, the Middle East, and North Africa.) It also makes sense to regard the willingness and ability of a country to pay for maintenance—an ongoing cost of road use—as a test of good internal management. There naturally are exceptions, most obviously when countries have suffered major calamities, when the structure of demand has changed considerably, or when the policies of lenders are distorting factors. None of these exceptions will, however, justify lending for new construction if the existing roads are in serious disrepair. If donors and lenders restrict financing to the foreign exchange cost of projects, and especially if they show a strong preference for new construction, they tempt recipient countries to divert their limited funds to such projects as leverage to gain more foreign aid.

Box 4-1. Earmarked Road Funds in the Central African Republic

In the 1960s and 1970s the Central African Republic made two unsuccessful attempts to earmark funds for roads. The first road fund was subject to so much discretion that the earmarking had no practical effect, and the fund was abandoned after three years. The second fund, set up in 1970 in connection with the World Bank's first road project, was designed to avoid the earlier shortcomings. But the amounts earmarked were inadequate, payments were erratic, and more money had to be sought through budgetary appropriations.

A third road fund, instituted in 1981 in connection with the fourth highway project, is still functioning. As a public establishment with financial autonomy, the fund has the sole function of financing road maintenance. Revenues come from a fuel tax, which the government adjusts yearly to ensure the fund's capacity to do its work. The fund is under the control of a ministerial management committee, on which road users are represented through the Chamber of Commerce.

This third road fund has also had problems, but none fatal. At one time it had difficulty collecting the revenues. At another the government forced the fund to pay for a project outside its mandate. Despite these and other problems the fund has improved road maintenance by raising the level, and increasing the regularity, of funding.

Table 4-5. External Assistance for Highways, 1981–84

Source	Millions of dollars	Percentage distribution by major components: New construction, improvements	Rehabilitation, reconstruction	Maintenance	Technical assistance[a]
World Bank	4,344	43	34	13	10
Other multilateral	2,889	n.a.	n.a.	n.a.	n.a.
AfDB, ABEDA, AsDB, IDB, IsDB, OPEC Fund[b]	(1,892)	59	30	10	1[c]
Bilateral (DAC)[d]	1,529	n.a.	n.a.	n.a.	n.a.
France, Federal Rep. of Germany, and Japan	(864)	62	25	8	5
Bilateral (other)	450	94	5	1	..

n.a. Not available.
.. Negligible.
a. Mostly for maintenance.
b. African Development Bank, Arab Bank for Economic Development in Africa, Asian Development Bank, Inter-American Development Bank, Islamic Development Bank, Organization of the Petroleum Exporting Countries' Fund.
c. Self-standing technical assistance; project-related technical assistance is not included.
d. Development Assistance Committee.

Box 4-2. World Bank Lending in Chile

Until 1985 World Bank lending for roads in Chile was mainly for individual construction projects. By 1985, however, the rapidly increasing need for road maintenance was already more than Chile could handle with its central funding and its decentralized institutional arrangements. The municipal governments that were responsible for 70 percent (56,000 kilometers) of the network lacked the technical, managerial, and financial resources needed for the task.

On advice from the Bank the central road agency (Vialidad) decided to resume gradually the responsibility for local roads and to use private contractors wherever they were competitive. The Bank's Highway Design and Maintenance Standards Model was used for comprehensive sector planning. The central road maintenance budget was to be increased from $78 million for 1986 to $123 million for 1988, with two-thirds of the investment budget reallocated to rehabilitation and reconstruction ($44 million a year).

To support these moves and the 1986–88 road investment and maintenance program, the Bank provided a sector loan of $140 million (21 percent of the program). Disbursements from the loan are tied to work on maintenance to ensure timely execution of this high-priority program. The Bank also participated in a parallel $400 million loan and worked with other lenders and suppliers to finance the rest of the program.

Under these conditions it is not surprising that maintenance is neglected, especially in the poorest countries, where foreign funding plays a big part in determining the allocation of resources. Maintenance work is then starved of the imported fuel, bitumen, and spare parts needed for the efficient use of equipment and labor. In short, the incentives are biased against preventive maintenance and thereby contribute to the premature deterioration of assets.

To halt the deterioration of roads in developing countries, all major lending agencies will have to liberalize their policies on lending for maintenance. They will also have to coordinate their policies in each country, instead of pursuing disparate and sometimes conflicting goals. As a first step toward coordination the various lenders need to agree on a comprehensive road program with the recipient country. To ensure fiscal discipline in the long run, all parties should scrutinize the implications of such a program: the capital and current budgets, the relative priorities of different parts of the program, and the size of the program in relation to the resources available from domestic and foreign sources. This should make it easier to coordinate assistance to make the most effective use of resources.

Chile shows what such a coordinated program of highway sector lending can achieve (see box 4-2). The requirements will differ in each country, so the content and relative size of internal and external contributions will also differ. For countries at the hard core of the road problem, the requirements in each dimension of the problem (money, technical skills, and administrative capability) are greater than can be met without assistance. For these countries the need for concerted action with donors is particularly great, since there is so little margin for waste.

5

Conclusions and Policy Recommendations

The conclusions and recommendations brought together in this chapter are based on three considerations: the increasing rate of road deterioration, the insulation of road authorities from the consequences of poor maintenance, and the huge costs and financial requirements involved.

The dynamics of road deterioration have much to do with the road maintenance problem. Paved roads do not deteriorate at a uniform rate. During an initial phase of several years deterioration is minor, but it accelerates rapidly thereafter. Casual observation of road surfaces gives little warning of the imminence of the critical phase during which road conditions begin to deteriorate rapidly. If maintenance is neglected, road users bear the brunt of the increase in total transport costs (the sum of infrastructure and vehicle operating costs), since the share of agency costs in the total cost of transport is small. Although vehicle operating costs constitute the dominant share of the total costs of road transport, improvements in the condition of uncongested roads save less in vehicle operating costs than previously estimated. Project analysts therefore have sometimes erred by crediting road investments with greater benefits than are justified. Meanwhile, road authorities have often erred by ignoring the effect of neglected maintenance on user costs. For road paving, moreover, the two errors do not cancel each other out; they reinforce one another. Paving is done before it is warranted, and then the pavements are neglected. The pavements become more and more costly to repair, and this leads to further neglect and premature failure.

Good choices in road management depend on many factors: climate, input prices, expected traffic flows, vehicle types and axle loads, existing road characteristics and conditions, efficiency of maintenance work, available resources and the opportunity cost of capital, and attitudes toward different risks. Because these factors vary from place to place, universal prescriptions could lead to many more mistakes than successes, and thus specific solutions are needed for each country. Nevertheless, some general conclusions emerge from the empirical research of the past decade.

Road planning and maintenance

- Gravel roads are more economical than paved roads where traffic volumes are low, the climate is not extreme, construction materials are not especially scarce, and adequate maintenance can be expected. This is true even for traffic volumes substantially higher than the previously assumed limits for these roads. The uncertainty surrounding some of the assumptions on which a decision to pave has to be based allows for a broad range of cost tradeoffs in which the break-even traffic volume for paving varies from less than 100 vehicles a day to more than 400, depending on the tradeoff. Decisions should therefore be guided by prudence and be based on a careful assessment of local conditions and of the likelihood that the road will indeed be adequately maintained.

- According to present knowledge, some paved roads should have been left unpaved because they carry so little traffic. Rather than maintain such roads at normal standards, it may be economical, when funds are limited, to let them deteriorate and simply use low-cost patching to keep them usable.
- If a road carrying more than about 500 vehicles a day is to be paved or strengthened, and if axle loads are hard to control, the economic savings from staged construction of the pavement are likely to be less than the cost of premature pavement failure. Thus countries that have difficulty enforcing load limits should build roads to higher initial standards, even though this normally means building fewer roads.
- Because of the nonlinear pattern of deterioration of paved roads, the resurfacing of newer roads can be deferred with only a small penalty—but only if those roads are not too close to their critical age and not heavily traveled. If the roads are somewhat older or traffic is heavier, the deferral of resurfacing could cause the pavements to break apart and make costly reconstruction necessary later on.
- In ranking the factors affecting maintenance choices, traffic volume is generally more important than road condition. So when budgets are severely constrained, across-the-board cutbacks may not be the answer. It may be better to maintain high-volume roads in fair or good condition and to reduce substantially the maintenance of some low-volume roads.
- Because the deterioration of paved roads is insidious, a road maintenance agency must regularly monitor the condition of roads so as not to delay maintenance beyond the point at which costs rise steeply. The agency must also monitor the volume and mix of traffic and axle loads to determine priorities for investment and maintenance. An effective management information system that covers these conditions as well as the agency's equipment, supplies, and personnel is a basic requirement for adequate planning and deployment of resources.
- For maximum economy, road maintenance policy should be coordinated with road design and construction planning, and the life-cycle costs of the roads should be balanced against the operating costs of the vehicles using them. This coordination requires a good data base, capable staff, and sound analytical techniques. Appropriate models and information management systems exist for such analyses. Their use will not prevent errors that result from bad data or incorrect traffic forecasts but may help to avoid the errors of oversimplification.

Institutional development

- Inadequate maintenance in developing countries has various causes, but only institutional failure can explain the extent of the inadequacy. At the heart of this failure is the absence of public accountability. All activities to strengthen institutions, enhance incentives, and improve the internal workings of road agencies should be judged by their ability to increase accountability. The road agency itself should be subject to an independent system of auditing and inspection.
- The nature of road deterioration and the separation of road management from road use have sheltered road authorities from public pressures and market signals. Both user groups and highway administrations should stimulate public awareness and communicate their needs and problems to policymakers.
- To limit the potential for conflict between the planning and control function of the road authority and the work execution function, the two should be separated. The government should minimize its direct role in work execution, even for routine maintenance, and transfer that responsibility to independent entities operating in a competitive environment that encourages managerial flexibility and efficiency.

Financing

- In countries with a backlog of roads needing rehabilitation and in those with young roads approaching the age when maintenance requirements multiply, adequate resources should be brought to bear on the maintenance problem before the roads get worse. This focus often requires reallocating funds from new construction to rehabilitation and maintenance. Ways of increasing the total road budget should be sought; increased user fees and taxes, possibly earmarked for rehabilitation and maintenance, should be considered. For many countries, external financing will also be needed—without it the serviceable network will have to contract.
- In many countries road allocations will have to be transferred from new construction to maintenance unless the total budget can be increased. Where budgets for the two purposes are separate or where a single authority cannot reallocate funds within the total, road resurfacing and rehabilitation should be classed as a capital expenditure.

World Bank Policy

Recommendations for World Bank policy must distinguish between principles that apply to all highway

Box 5-1. A Diagnostic Framework for Determining External Assistance Policy in the Road Sector

The country examples used in this diagnostic framework represent conditions in 1984.

Category I. In these countries the institutional capacity and past maintenance effort have generally been adequate. These countries now need to adjust policies and expenditures to meet emerging maintenance requirements, particularly for new networks. They also need to continue to make institutional and technological improvements and find ways to increase operational efficiency. *Examples:* Chile, Republic of Korea, Malawi, Niger, Yemen Arab Republic.

Category II. In these countries the funding for maintenance has been insufficient. They urgently need to reallocate domestic and external resources within and to the road sector. They also need to devote greater emphasis to policy reform to expand their institutional capacity. *Examples:* Brazil, Indonesia, Kenya, Nigeria, Yugoslavia.

Category III. In these countries the institutional capacity has been grossly inadequate. They urgently need to mobilize substantial external financial and institutional assistance. They must give high priority to the coordination of aid programs and emphasize institutional reform.

A. This subcategory of countries with relatively new networks must give priority to resurfacing and strengthening paved and unpaved roads and to building institutional capacity. *Examples:* Benin, Burundi, Liberia, Mali, Nepal, Senegal.

B. This subcategory of countries must give priority to restoring their aging road infrastructure and to building the institutional capacity in the road sector to aid economic recovery. *Examples:* Bolivia, Ghana, Laos, Madagascar, Sierra Leone, Tanzania.

Category IV. In these countries, the networks and maintenance technology are obsolete. They need to mobilize domestic and external resources for modernization. They also need to place emphasis on technology transfer, institutional improvements, and the development of skills. *Examples:* Bangladesh, Burma, China, India, Pakistan.

lending and principles that apply to different countries according to their capacity for financing estimated maintenance needs and the capacity of their institutions. A review of information, backed by the experience of Bank staff, suggests that countries can be placed in four main classes according to:

- The state of the road networks
- The financial requirements for maintenance and rehabilitation and the country's ability to meet those requirements
- The possibility of reallocating recurrent funds for roads without causing severe disruptions
- The institutional capacity to absorb more funding for maintenance and rehabilitation.

The four categories are reasonably exhaustive and cover cases that the Bank is likely to encounter in the next few years. Each category can be exemplified by countries for which adequate information is available (see box 5-1).

- Category I countries have, for the most part, used resources for road investments and maintenance in a cost-effective manner and now have a serviceable road network. Sustaining past trends will depend on the ability of these countries to adjust their road priorities to changing circumstances and to maintain their existing institutional capacity. Provided these conditions are met and barring unforeseen events, countries in this category should suffer no serious road transport constraints over the next five to ten years. The main emphasis of external assistance should be on institutional improvements, technology transfer, and operational efficiency.
- Category II countries have underfunded road maintenance, with the result that it has been inadequate in quality or quantity, or both. They could, however, rectify past inadequacies over five to ten years by reallocating resources to maintenance, improving the efficiency of their operations and management, securing more external assistance, and, in some cases, increasing the road budget.
- Category III countries have backlogs of rehabilitation and maintenance so large relative to domestic funds, personnel, and technology that corrective action will take substantial time, effort, and external assistance. This category is divided into countries in which preserving a young network is the primary need (IIIA) and countries with older networks needing massive rehabilitation (IIIB).
- Category IV includes China and most of the Indian subcontinent. The common characteristic is an extensive and obsolete road network in need of modernization to meet the burgeoning demand for road transport. With few exceptions, these countries have not neglected maintenance. But their aged road networks and outmoded maintenance

technology seriously constrain good maintenance practice. These countries need to mobilize substantial domestic and external financial resources to meet the growing needs of their road networks.

A common requirement for all four categories, and one of great importance to Bank policy, is the reallocation of domestic and external resources to balance new construction with maintenance, rehabilitation, and betterment. Reallocation will vary according to each country's circumstances within the broad limits for each category. In most countries, reallocating the road budget will leave fewer resources for new construction, so that new investment priorities will have to be established. In some countries, moreover, no amount of reallocation will suffice; nor will the economic situation permit additions to the road budget. In such circumstances the network's quality and extent will have to be reduced. If such a contraction appears inescapable, the objective of the Bank's analytic work will be to establish priorities for essential maintenance and restoration.

The Bank's sector and economic work in transport will refine the assignment of countries to the four categories. Moreover, the analysis of a country's road sector will be essential to formulating the Bank's recommendations, particularly for countries having the most critical problems. Because restoration and maintenance needs vastly exceed the resources available for this purpose in most countries, public investment and expenditure reviews will recommend the division of road expenditures among new construction, restoration, and maintenance. These reviews will also evaluate the financial and institutional capacity for coping with the future maintenance needs of new road investments and propose cost-effective investment and maintenance strategies.

Bank lending for roads will be conditional on each country's achievement of an acceptable distribution of expenditures among new construction, restoration, and maintenance.

- For countries in category III, lending will normally be confined to road maintenance and restoration and be made contingent upon the country's applying its entire road budget, including external assistance, to maintenance and restoration. Exceptions to this condition will be made where roads are needed to exploit agricultural and mineral resources in the context of identifiable investment projects.
- For countries in category II, lending will be conditional on periodic agreement between the government and the Bank about the division of funds among new construction, restoration, and maintenance. Funds will be committed or released in tranches and made conditional on reaching the interim objectives of agreed-on programs.
- In Bank appraisals of road construction and betterment, the probability of a road's being maintained to acceptable standards will enter explicitly into the calculation of a project's expected net benefits and will be determined in large part by the country's past record of road maintenance.

Because so much capital is at risk and the economic outcomes are so sensitive to country differences in networks, traffic, and other circumstances, the Bank will require that road agencies have an adequate road management system—or a phased, monitorable program for establishing one. To improve efficiency and reduce the potential for conflict between the planning and execution functions of the road authority, the Bank will encourage maintenance work by (private or public) entities outside the road authority that operate according to commercial principles and, preferably, in a competitive environment. In addition, the Bank will support schemes to increase awareness of the need for management systems and for adequate resources for rehabilitation and maintenance. These schemes will focus on efforts to educate government officials and to make the public aware of the consequences of neglecting maintenance. Such efforts will include regular publication of the data obtained from monitoring road conditions.

The Bank will also assess progress in the education and public awareness components of Bank projects and in the transfer of maintenance work to entities outside the road agency. It shall periodically review the four-category classification of countries and make appropriate adjustments on the basis of new evidence or the findings of its operational staff.

Action by the International Community

In financing highways, external agencies should emphasize rehabilitation and maintenance in countries in categories II and III and modernization in countries in category IV. They should limit their financing of new construction largely to countries in categories I and IV—and even then provide funds only through integrated programs for construction, maintenance, rehabilitation, and modernization. In addition, all external agencies involved in road sector activities in any country in category II or III should require the recipient government to establish internal administrative mechanisms to coordinate and monitor external assistance programs. Consultative group or round table meetings can effectively help governments to achieve this objective.

The data base needed for identifying the factors that influence road deterioration and the effects of different maintenance processes should be substantially strengthened and refined. Road research institutions and highway authorities in developed and developing countries should continue research on the multidimensional issues of road deterioration—technical, institutional and financial—and should support international exchanges of data and technology. In addition, external agencies should provide technical and financial support for the compilation of international statistics on road conditions. Such a compilation is essential if worldwide trends are to be detected and reliable judgments made about the relative performance of countries. The United Nations Statistical Office—or an organization such as the Permanent International Association of Road Congresses or the International Road Federation—could assume responsibility for compiling these statistics. Also recommended is the annual publication of statistics on the sources and uses of external aid for road development.

APPENDIX A

Statistical Tables

Table A-1. Basic Characteristics of Road Networks by Region

Item	*Eastern and Southern Africa*	*Western Africa*		*East Asia and the Pacific*		*South Asia*		*Europe, the Middle East, and North Africa*	*Latin America and the Caribbean*		*Total*
		All	*Excluding Nigeria*	*All*	*Excluding China*	*All*	*Excluding India*		*All*	*Excluding Brazil and Mexico*	
Number of countries	19	20	19	7	6	6	5	14	19	17	85
Area (thousands of square kilometers)	11,051	8,891	7,967	13,184	3,623	5,120	1,922	6,476	18,859	8,374	63,581
GNP, 1984 (billions of dollars)	51.2	104.7	34.3	600.4	281.4	257.5	62.7	338.1	583.9	199.1	1,935.9
Population, 1984 (millions)	201	186	90	1,350	221	1,008	259	232	350	141	3,327
GNP per capita											
Median, 1984 (dollars)	310	290	270	710	785	220	180	1,795	1,190	1,160	—
Average annual growth rate, 1975–85 (percent)	-0.1	-1.0	-0.9	3.4	2.5	2.4	1.8	3.1	0.0	-0.1	—
Total road network											
Length (thousands of kilometers)	588.3	430.9	322.9	1,539.6	571.2	1,680.7	180.7	1,051.0	2,212.1	874.1	7,502.6
Percentage paved	7.7	12.6	10.3	18.1	16.9	31.1	26.7	29.3	11.0	11.8	19.4
Density in kilometers per:											
100 square kilometers	5.3	4.8	4.1	11.7	15.8	32.8	9.4	16.2	11.7	10.4	11.8
1,000 population	2.9	2.3	3.6	1.1	2.6	1.7	0.7	4.5	6.3	6.2	2.3
$1 million of GNP	11.5	4.1	9.4	2.6	2.0	6.5	2.9	3.1	3.8	4.4	3.9
Main roads											
Length (thousands of kilometers)	190.5	144.5	115.4	450.9	196.6	217.1	89.6	303.7	511.7	193.7	1,818.4
Percentage paved	24.6	37.3	27.8	61.4	52.8	80.3	56.0	74.5	49.2	44.3	56.8
Density in kilometers per:											
100 square kilometers	1.7	1.6	1.4	3.4	5.4	4.2	4.7	4.7	2.7	2.3	2.9
1,000 population	0.9	0.8	1.3	0.3	0.9	0.2	0.3	1.3	1.5	1.4	0.5
$1 million of GNP	3.7	1.4	3.4	0.8	0.7	0.8	1.4	0.9	0.9	1.0	0.9
Main paved roads											
Length (thousands of kilometers)	46.9	53.9	32.1	276.9	103.8	174.3	50.2	226.3	251.8	85.8	1,030.0
Density (kilometers per 100 square kilometers)	0.8	0.9	0.5	9.5	5.6	7.4	2.3	10.6	6.8	2.0	29.5
Replacement value of main network											
Average cost per kilometer (dollars)											
Paved	255,000	245,000	245,000	300,000	300,000	180,000	180,000	280,000	260,000	260,000	—
Unpaved	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	—
Value (billions of dollars)											
Paved	12.0	13.2	7.9	83.1	31.1	31.4	9.0	63.4	65.5	22.3	268.4
Unpaved	5.7	3.6	3.3	7.0	3.7	1.7	1.6	3.1	10.4	4.3	31.5
Total	17.7	16.8	11.2	90.0	34.9	33.1	10.6	66.4	75.9	26.6	299.9
As a percentage of GNP	34.6	16.1	32.6	15.0	12.4	12.9	16.9	19.7	13.0	13.4	15.5

— Not applicable.
Source: World Bank surveys and reports.

Table A-2. Road Networks by Country and Region, 1984

Country and region	Population (millions)	Area (thousands of square kilometers)	GNP per capita: 1984 (dollars)	GNP per capita: Average annual growth rate, 1975–85 (percent)	Total GNP (millions of dollars)	Total network: Length (kilometers)	Total network: Density in kilometers per: 100 square kilometers	Total network: Density in kilometers per: 1,000 population	Total network: Density in kilometers per: $1 million of GNP	Ma: Length (kilometer
Eastern and Southern Africa										
Botswana	1.0	600	960	7.9	960	13,000	2.2	13.0	13.5	8,026
Burundi	4.6	28	220	0.9	1,012	5,400	19.3	1.2	5.3	2,900
Comoros	0.4	2	340	n.a.	129	850	42.5	2.2	6.6	762
Djibouti	0.4	22	358	n.a.	129	2,800	12.7	7.8	21.7	1,100
Ethiopia	42.2	1,222	110	−0.9	4,642	43,200	3.5	1.0	9.3	13,600
Kenya	19.6	583	310	0.1	6,076	55,000	9.4	2.8	9.1	25,300
Lesotho	1.5	30	530	3.7	795	4,000	13.3	2.7	5.0	2,010
Madagascar	9.9	587	260	−3.4	2,574	50,000	8.5	5.1	19.4	10,150
Malawi	6.8	118	180	0.2	1,224	13,280	11.3	2.0	10.8	5,571
Mauritius	1.1	2	1,090	2.6	1,199	2,795	139.8	2.5	2.3	1,787
Rwanda	5.8	26	280	1.0	1,624	10,000	38.5	1.7	6.2	4,000
Somalia	5.2	638	260	−0.3	1,352	21,600	3.4	4.2	16.0	9,644
Sudan	21.3	2,506	360	−0.4	7,668	19,110	0.8	0.9	2.5	7,000
Swaziland	0.7	17	800	−0.2[b]	568	2,821	16.6	4.0	5.0	2,724
Tanzania	21.5	945	210	−1.7	4,515	53,600	5.7	2.5	11.9	17,700
Uganda	15.0	236	230	−3.3	3,450	27,037	11.5	1.8	7.8	5,691
Zaire	29.7	2,345	140	−3.9	4,158	145,000	6.2	4.9	34.9	40,900
Zambia	6.4	753	470	−3.7	3,008	35,000	4.6	5.5	11.6	20,653
Zimbabwe	8.1	391	760	−1.3	6,156	85,000	21.7	10.5	13.8	11,003
Total	201.2	11,051	—	—	51,239	589,493	5.3	2.9	11.5	190,521
Average	—	—	255	−0.1	—	—	—	—	—	—
Western Africa										
Benin	3.9	113	270	0.6	1,053	7,500	6.6	1.9	7.1	4,926
Burkina Faso	6.6	274	160	0.9	1,056	11,200	4.1	1.7	10.6	6,300
Cameroon	9.9	475	760	3.9	7,524	64,905	13.7	6.6	8.6	13,500
Central African Rep.	2.5	623	260	−1.4	650	22,600	3.6	9.0	34.8	5,250
Chad	4.9	1,284	80	−7.7[b]	392	31,300	2.4	6.4	79.8	3,800
Congo	1.8	342	1,140	2.2	2,052	11,000	3.2	6.1	5.4	7,000
Côte d'Ivoire	9.9	322	610	−2.2	6,039	47,880	14.9	4.8	7.9	13,680
Equatorial Guinea	0.4	28	180	n.a.	67	1,540	5.5	4.2	23.1	1,090
Gambia, The	0.7	11	260	−1.7	185	2,388	21.7	3.4	12.9	1,209
Ghana	12.3	239	350	−1.9	4,305	28,400	11.9	2.3	6.6	14,130
Guinea	5.9	246	330	0.2[b]	1,947	14,000	5.7	2.4	7.2	4,550
Guinea-Bissau	0.9	36	180	−2.1[b]	158	4,040	11.2	4.6	25.5	2,300
Liberia	2.1	111	470	−3.7	987	7,560	6.8	3.6	7.7	3,945
Mali	7.3	1,240	140	0.0	1,022	13,500	1.1	1.8	13.2	5,222
Mauritania	1.7	1,031	450	−0.4	765	7,500	0.7	4.4	9.8	2,480
Niger	6.2	1,267	190	−1.1	1,178	19,000	1.5	3.1	16.1	6,369
Nigeria	96.5	924	730	−3.3	70,445	108,000	11.7	1.1	1.5	29,100
Senegal	6.4	196	480	−1.3	3,072	11,700	6.0	1.8	3.8	9,700
Sierra Leone	3.7	72	310	−0.3	1,147	9,924	13.8	2.7	8.7	7,040
Togo	2.9	57	250	−1.5	725	7,000	12.3	2.4	9.7	2,921
Total	186.5	8,891	—	—	104,769	430,937	4.8	2.3	4.1	144,512
Average	—	—	562	−1.0	—	—	—	—	—	—
East Asia and the Pacific										
China	1,029.2	9,561	310	6.8	319,052	915,100	9.6	0.9	2.9	254,300
Indonesia	158.9	1,919	540	3.6	85,806	201,300	10.5	1.3	2.3	45,800
Korea, Rep. of	40.1	98	2,110	6.4	84,611	54,000	55.1	1.3	0.6	23,481
Malaysia	15.3	330	1,980	4.1	30,294	45,000	13.6	2.9	1.5	25,324
Papua New Guinea	3.4	462	710	−0.8	2,414	18,545	4.0	5.5	7.7	3,652
Philippines	53.4	300	660	0.1	35,244	155,669	51.9	2.9	4.4	53,864
Thailand	50.0	514	860	3.9	43,000	150,000	29.2	3.0	3.5	44,534
Total	1,350.3	13,184	—	—	600,421	1,539,614	11.7	1.1	2.6	450,955
Average	—	—	445	3.4	—	—	—	—	—	—
South Asia										
Bangladesh	98.1	144	130	1.7	12,753	15,000	10.4	0.2	1.2	10,900
Burma	36.1	677	180	3.9	6,498	27,983	4.1	0.8	4.3	25,400

network			Main paved network								Main unpaved network					
Density in kilometers per:			Length (kilometers)	Condition (percent)[a]			Portion constructed or improved in:				Length (kilometers)	Condition (percent)[a]			Portion constructed or improved in 1980–84	
							1980–84		1975–79							
100 square kilometers	1,000 population	$1 million of GNP		Good	Fair	Poor	Kilometers	Percent	Kilometers	Percent		Good	Fair	Poor	Kilometers	Percent
1.3	8.0	8.4	1,967	90	8	2	600	31	400	20	6,059	40	30	30	400	7
10.4	0.6	2.9	744	58	37	5	390	52	40	. 5	2,156	60	25	15	n.a.	n.a.
38.1	2.0	5.9	456	60	20	20	50	11	21	5	306	20	20	60	n.a.	n.a.
5.0	3.1	n.a.	300	30	60	10	24	8	n.a.	n.a.	800	10	10	80	n.a.	n.a.
1.1	0.3	2.9	3,800	33	34	33	485	13	n.a.	n.a.	9,800	33	34	33	n.a.	n.a.
4.3	1.3	4.2	6,000	32	52	16	1,400	23	1,600	27	19,300	66	17	17	358	2
6.7	1.3	2.5	398	25	35	40	n.a.	n.a.	n.a.	n.a.	1,612	20	50	30	n.a.	n.a.
1.7	1.0	3.9	4,890	20	30	50	300	6	450	9	5,260	20	20	60	n.a.	n.a.
4.7	0.8	4.6	2,004	50	35	15	270	13	913	46	3,567	30	35	35	400	11
89.4	1.6	1.5	1,610	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	177	n.a.	n.a.	n.a.	n.a.	n.a.
15.4	0.7	2.5	800	80	20	0	300	38	60	8	3,200	20	80	0	3,000	94
1.5	1.9	7.1	2,460	60	20	20	n.a.	n.a.	n.a.	n.a.	7,184	30	30	40	n.a.	n.a.
0.3	0.3	0.9	2,240	40	30	30	790	35	n.a.	n.a.	4,760	20	20	60	n.a.	n.a.
16.0	3.8	4.8	521	50	25	25	285	55	80	15	2,203	25	25	50	n.a.	n.a.
1.9	0.8	3.9	3,240	38	34	28	581	18	n.a.	n.a.	14,460	5	47	48	1,700	12
2.4	0.4	1.6	1,726	10	59	31	n.a.	n.a.	110	6	3,965	52	26	22	n.a.	n.a.
1.7	1.4	9.8	2,400	17	20	63	200	8	400	17	38,500	61	25	14	n.a.	n.a.
2.7	3.2	6.9	5,502	40	30	30	150	3	1,200	22	15,151	30	35	35	250	2
2.8	1.4	1.8	5,595	70	25	5	n.a.	n.a.	n.a.	n.a.	5,408	50	30	20	2,090	39
—	—	—	46,653	—	—	—	—	—	—	—	143,868	—	—	—	—	—
1.7	0.9	3.7	—	42	32	26	—	—	—	—	—	42	30	28	—	—
4.4	1.3	4.7	986	58	36	6	230	23	100	10	3,940	15	55	30	500	13
2.3	1.0	6.0	1,400	40	40	20	400	29	281	20	4,900	10	30	60	355	7
2.8	1.4	1.8	2,900	60	30	10	783	27	797	27	10,600	20	50	30	n.a.	n.a.
0.8	2.1	8.1	442	36	35	29	269	61	65	15	4,808	68	16	16	955	20
0.3	0.8	9.7	163	4	0	96	7	4	n.a.	n.a.	3,637	8	19	73	1,000	27
2.0	3.9	3.4	1,100	69	15	16	620	56	480	44	5,900	30	20	50	150	3
4.2	1.4	2.3	3,620	78	15	7	955	26	1,330	37	10,060	30	60	10	170	2
3.9	2.9	n.a.	485	26	0	74	n.a.	n.a.	80	16	605	0	0	100	n.a.	n.a.
11.0	1.7	6.5	447	27	50	23	210	47	30	7	762	30	42	28	310	41
5.9	1.1	3.3	5,782	12	27	61	126	2	n.a.	n.a.	8,348	17	48	35	n.a.	n.a.
1.8	0.8	2.3	1,145	51	35	14	201	18	85	7	3,405	13	22	65	975	29
6.4	2.6	14.5	485	2	65	33	30	6	30	6	1,815	n.a.	n.a.	n.a.	n.a.	n.a.
3.6	1.9	4.0	557	85	13	2	110	20	250	45	3,388	15	75	10	176	5
0.4	0.7	5.1	1,890	43	33	24	540	29	378	20	3,332	11	4	85	1,340	40
0.2	1.5	3.2	1,640	30	30	40	1,200	73	200	12	840	0	5	95	n.a.	n.a.
0.5	1.0	5.4	2,609	70	20	10	505	19	757	29	3,760	30	35	35	666	18
3.1	0.3	0.4	21,100	62	15	23	4,980	24	7,588	36	8,000	0	10	90	n.a.	n.a.
4.9	1.5	3.2	3,762	51	36	13	470	12	740	20	5,938	4	26	70	400	7
9.8	1.9	6.1	1,280	20	45	35	240	19	n.a.	n.a.	5,760	30	40	30	n.a.	n.a.
5.1	1.0	4.0	1,712	40	24	36	427	25	235	14	1,209	30	45	25	86	7
—	—	—	53,505	—	—	—	—	—	—	—	91,007	—	—	—	—	—
1.6	0.8	1.4	—	52	23	25	—	—	—	—	—	20	36	44	—	—
2.7	0.2	0.8	173,000	10	70	20	22,000	13	59,000	34	81,300	50	25	25	n.a.	n.a.
2.4	0.3	0.5	27,550	30	30	40	5,530	20	5,000	18	18,250	22	47	31	3,500	19
24.0	0.6	0.3	9,928	70	25	5	3,860	39	1,926	19	13,553	60	20	20	n.a.	n.a.
7.7	1.7	0.8	23,479	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1,845	n.a.	n.a.	n.a.	n.a.	n.a.
0.8	1.1	1.5	726	34	45	21	110	15	109	15	2,926	23	71	6	n.a.	n.a.
18.0	1.0	1.5	14,192	31	54	15	900	6	500	4	39,672	25	50	25	1,055	3
8.7	0.9	1.0	28,000	50	30	20	8,600	31	5,242	19	16,534	45	30	25	n.a.	n a.
—	—	—	276,875	—	—	—	—	—	—	—	174,080	—	—	—	—	—
3.4	0.3	0.8	—	20	59	21	—	—	—	—	—	41	34	25	—	—
7.6	0.1	0.9	6,210	15	40	45	1,180	19	60	1	4,690	10	40	50	n.a.	n.a.
3.8	0.7	3.9	8,400	0	50	50	n.a.	n.a.	n.a.	n.a.	17,000	0	50	50	n.a.	n.a.

(Table continues on the following page.)

Table A-2. *(continued)*

Country and region	Population (millions)	Area (thousands of square kilometers)	GNP per capita: 1984 (dollars)	GNP per capita: Average annual growth rate, 1975–85 (percent)	Total GNP (millions of dollars)	Total network: Length (kilometers)	Total network: Density in kilometers per: 100 square kilometers	Total network: Density in kilometers per: 1,000 population	Total network: Density in kilometers per: $1 million of GNP	Main: Length (kilometers)
India (national)	749.2	3,288	260	1.9	194,792	1,500,000	45.6	2.0	7.7	32,000
India (states)	—	—	—	—	—	—	—	—	—	95,500
Nepal	16.1	141	160	0.7	2,576	7,150	5.1	0.4	2.8	5,546
Pakistan	92.4	804	380	3.3	35,112	107,673	13.4	1.2	3.1	38,830
Sri Lanka	15.9	66	360	3.2	5,724	25,500	38.6	1.6	4.5	8,900
Total	1,007.8	5,120	—	—	257,455	1,683,306	32.9	1.7	6.5	217,076
Average	—	—	255	2.4	—	—	—	—	—	—
Europe, the Middle East, and North Africa										
Algeria	21.2	2,382	2,410	3.2	51,092	78,190	3.3	3.7	1.5	39,347
Cyprus	0.7	9	3,590	7.0	2,405	6,831	75.9	10.2	2.8	3,031
Egypt, Arab Rep. of	45.9	1,001	720	4.8	33,048	30,089	3.0	0.7	0.9	28,725
Hungary	10.7	93	2,100	5.1[b]	22,470	138,185	148.6	12.9	6.1	24,000
Morocco	21.4	447	670	1.4	14,338	57,692	12.9	2.7	4.0	19,080
Oman	1.1	300	6,490	4.4[b]	7,139	18,123	6.0	16.5	2.5	8,474
Portugal	10.2	92	1,970	1.6	20,094	52,031	56.6	5.1	2.6	19,031
Romania	22.7	238	2,290	n.a.	51,983	73,500	30.9	3.2	1.4	14,700
Syria	10.1	185	1,620	−0.2	16,362	26,200	14.2	2.6	1.6	15,700
Tunisia	7.0	164	1,270	2.6	8,890	78,190	47.7	11.2	8.8	16,900
Turkey	48.4	781	1,160	1.4	56,144	329,793	42.2	6.8	5.9	60,953
Yemen Arab Rep.	7.8	195	550	4.0	4,290	25,028	12.8	3.2	5.8	3,028
Yemen, People's Dem. Rep. of	2.0	333	550	5.2	1,100	7,100	2.1	3.6	6.5	1,887
Yugoslavia	23.0	256	2,120	2.6	48,760	130,000	50.8	5.7	2.7	48,880
Total	232.2	6,476	—	—	338,115	1,050,952	16.2	4.5	3.1	303,736
Average	—	—	1,456	3.1	—	—	—	—	—	—
Latin America and the Caribbean										
Argentina	30.1	2,767	2,230	−1.9	67,123	212,305	7.7	7.1	3.2	36,505
Barbados	0.3	0	4,340	1.6	1,128	1,670	388.4	6.4	1.5	1,367
Belize	0.2	23	1,150	3.6[b]	184	2,000	8.7	12.5	10.9	1,871
Bolivia	6.2	1,099	540	−4.0	3,348	39,824	3.6	6.4	11.9	9,382
Brazil (federal)	132.6	8,512	1,720	1.2	228,072	1,316,343	15.5	9.9	5.8	64,642
Brazil (states)	—	—	—	—	—	—	—	—	—	162,596
Chile	11.8	757	1,700	0.9	20,060	79,000	10.4	6.7	3.9	22,831
Colombia	28.4	1,139	1,390	1.7	39,476	77,200	6.8	2.7	2.0	24,397
Costa Rica	2.5	51	1,190	−0.3	2,975	28,500	55.9	11.4	9.6	4,789
Dominican Rep.	6.1	49	970	0.2	5,917	17,200	35.1	2.8	2.9	3,475
Ecuador	9.1	284	1,150	0.3	10,465	37,910	13.3	4.2	3.6	8,400
Guatemala	7.7	109	1,160	−3.3	8,932	18,426	16.9	2.4	2.1	10,641
Haiti	5.4	28	320	0.7	1,728	4,000	14.3	0.7	2.3	2,473
Honduras	4.2	112	700	0.4	2,940	12,058	10.8	2.9	4.1	6,018
Jamaica	2.2	11	1,150	−4.0	2,530	17,700	160.9	8.0	7.0	4,750
Mexico (federal)	76.8	1,973	2,040	0.6	156,672	212,626	10.8	2.8	1.4	43,500
Mexico (states)	—	—	—	—	—	—	—	—	—	47,300
Panama	2.1	77	1,980	1.3	4,158	8,665	11.3	4.1	2.1	8,400
Paraguay	3.3	407	1,240	3.7	4,092	24,329	6.0	7.4	5.9	11,241
Peru	18.2	1,285	1,000	−2.5	18,200	58,516	4.6	3.2	3.2	27,300
Uruguay	3.0	176	1,980	−1.0	5,940	49,813	28.3	16.6	8.4	9,813
Total	350.2	18,859	—	—	583,940	2,218,085	11.8	6.3	3.8	511,691
Average	—	—	1,668	−0.03	—	—	—	—	—	—
Total for all six regions (85 countries)	3,328.2	63,581	—	—	1,935,939	7,512,387	—	—	—	1,818,491
Average	—	—	582	—	—	—	—	—	—	—

—Not applicable.
n.a. Not available.
a. Percentage of network in each category.
b. 1973–83.
Source: World Bank surveys and reports.

network			Main paved network								Main unpaved network					
Density in kilometers per:				Condition (percent)[a]			Portion constructed or improved in:					Condition (percent)[a]			Portion constructed or improved in 1980–84	
							1980–84		1975–79							
100 square kilometers	*1,000 population*	*$1 million of GNP*	*Length (kilometers)*	*Good*	*Fair*	*Poor*	*Kilometers*	*Percent*	*Kilometers*	*Percent*	*Length (kilometers)*	*Good*	*Fair*	*Poor*	*Kilometers*	*Percent*
1.0	0.0	0.2	31,600	20	45	35	2,500	8	3,000	9	400	20	40	40	n.a.	n.a.
—	—	—	91,200	20	45	35	n.a.	n.a.	n.a.	n.a.	4,300	20	40	40	n.a.	n.a.
3.9	0.3	2.2	2,500	40	35	25	584	23	376	15	3,046	15	45	40	300	10
4.8	0.4	1.1	24,142	18	50	32	1,940	8	2,500	10	14,688	5	25	70	n.a.	n.a.
13.5	0.6	1.6	8,900	10	40	50	50	1	100	1	0	0	0	0	n.a.	n.a.
—	—	—	172,952	—	—	—	—	—	—	—	44,124	—	—	—	—	—
4.2	0.2	0.8	—	19	45	36	—	—	—	—	—	6	39	55	—	—
1.7	1.9	0.8	32,480	40	32	28	n.a.	n.a.	1,070	3	6,867	25	50	25	n.a.	n.a.
33.7	4.5	1.3	2,938	38	38	24	253	9	400	14	93	0	50	50	n.a.	n.a.
2.9	0.6	0.9	15,081	39	33	28	n.a.	n.a.	n.a.	n.a.	13,644	n.a.	n.a.	n.a.	n.a.	n.a.
25.8	2.2	1.1	24,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0	n.a.	n.a.	n.a.	n.a.	n.a.
4.3	0.9	1.3	14,816	20	44	36	1,625	11	55	0	4,264	n.a.	n.a.	n.a.	n.a.	n.a.
2.8	7.7	1.2	3,292	66	20	14	1,950	59	900	27	5,182	n.a.	n.a.	n.a.	690	13
20.7	1.9	0.9	17,900	50	30	20	1,400	8	1,000	6	1,131	40	40	20	200	18
6.2	0.6	0.3	14,000	69	21	10	810	6	1,670	12	700	39	37	24	n.a.	n.a.
8.5	1.6	1.0	11,700	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	4,000	n.a.	n.a.	n.a.	n.a.	n.a.
10.3	2.4	1.9	9,140	55	36	9	1,000	11	900	10	7,760	30	40	30	2,300	30
7.8	1.3	1.1	38,449	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	22,504	n.a.	n.a.	n.a.	n.a.	n.a.
1.6	0.4	0.7	2,048	70	20	10	450	22	300	15	980	40	30	30	210	21
0.6	0.9	1.7	1,650	27	69	4	637	39	602	36	237	33	33	34	n.a.	n.a.
19.1	2.1	1.0	36,630	30	41	29	1,358	4	441	1	12,250	30	50	20	n.a.	n.a.
—	—	—	224,124	—	—	—	—	—	—	—	79,612	—	—	—	—	—
4.7	1.3	0.9	—	41	35	24	—	—	—	—	—	30	46	24	—	—
1.3	1.2	0.5	27,056	35	21	44	n.a.	n.a.	2,280	8	9,449	20	40	40	n.a.	n.a.
317.9	5.3	1.2	1,367	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0	n.a.	n.a.	n.a.	n.a.	n.a.
8.1	11.7	10.2	442	32	48	20	n.a.	n.a.	n.a.	n.a.	1,429	2	43	55	n.a.	n.a.
0.9	1.5	2.8	1,351	21	48	31	120	9	n.a.	n.a.	8,031	20	30	50	n.a.	n.a.
0.8	0.5	0.3	45,291	30	42	28	6,570	15	n.a.	n.a.	19,351	30	42	28	n.a.	n.a.
—	—	—	55,887	n.a.	n.a.	n.a.	8,000	14	8,000	14	106,709	n.a.	n.a.	n.a.	n.a.	n.a.
3.0	1.9	1.1	8,964	33	56	11	630	7	750	8	13,867	7	75	18	500	4
2.1	0.9	0.6	9,620	42	37	21	1,730	18	1,953	20	14,777	42	37	22	1,150	8
9.4	1.9	1.6	3,044	22	29	49	890	29	240	8	1,745	8	7	85	n.a.	n.a.
7.1	0.6	0.6	2,485	52	10	38	800	32	200	8	990	0	22	78	200	20
3.0	0.9	0.8	3,380	53	19	28	270	8	790	23	5,020	65	10	25	n.a.	n.a.
9.8	1.4	1.2	3,043	7	50	43	243	8	162	5	7,598	11	62	27	n.a.	n.a.
8.8	0.5	1.4	606	0	100	0	130	21	130	21	1,867	10	42	48	n.a.	n.a.
5.4	1.4	2.0	1,614	50	43	7	n.a.	n.a.	282	17	4,404	50	38	12	n.a.	n.a.
43.2	2.2	1.9	4,365	10	73	17	222	5	64	1	385	1	56	43	254	66
2.2	0.6	0.3	40,520	85	10	5	4,000	10	2,000	5	2,980	30	50	20	n.a.	n.a.
—	—	—	24,200	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	23,100	n.a.	n.a.	n.a.	n.a.	n.a.
10.9	4.0	2.0	3,094	36	54	10	330	11	450	15	5,306	8	68	24	n.a.	n.a.
2.8	3.4	2.7	1,695	73	22	5	340	20	470	28	9,546	44	38	18	780	8
2.1	1.5	1.5	7,178	24	24	52	920	13	70	1	20,122	10	30	60	n.a.	n.a.
5.6	3.3	1.7	6,445	26	59	15	n.a.	n.a.	n.a.	n.a.	3,368	0	75	25	n.a.	n.a.
—	—	—	251,647	—	—	—	—	—	—	—	260,044	—	—	—	—	—
2.7	1.5	0.9	—	44	32	24	—	—	—	—	—	24	43	33	—	—
—	—	—	1,025,756	—	—	—	—	—	—	—	792,735	—	—	—	—	—
2.9	0.5	0.9	—	32	42	26	—	—	—	—	—	31	36	33	—	—

APPENDIX B

Exploring Cost-Effective Options for Road Investment and Maintenance

This appendix presents a fuller technical explanation of the findings reported in the main text concerning the economic consequences of different road investment and maintenance strategies. It is based on an investigation of the engineering-economic aspects of road deterioration by Bhandari and others (1987).

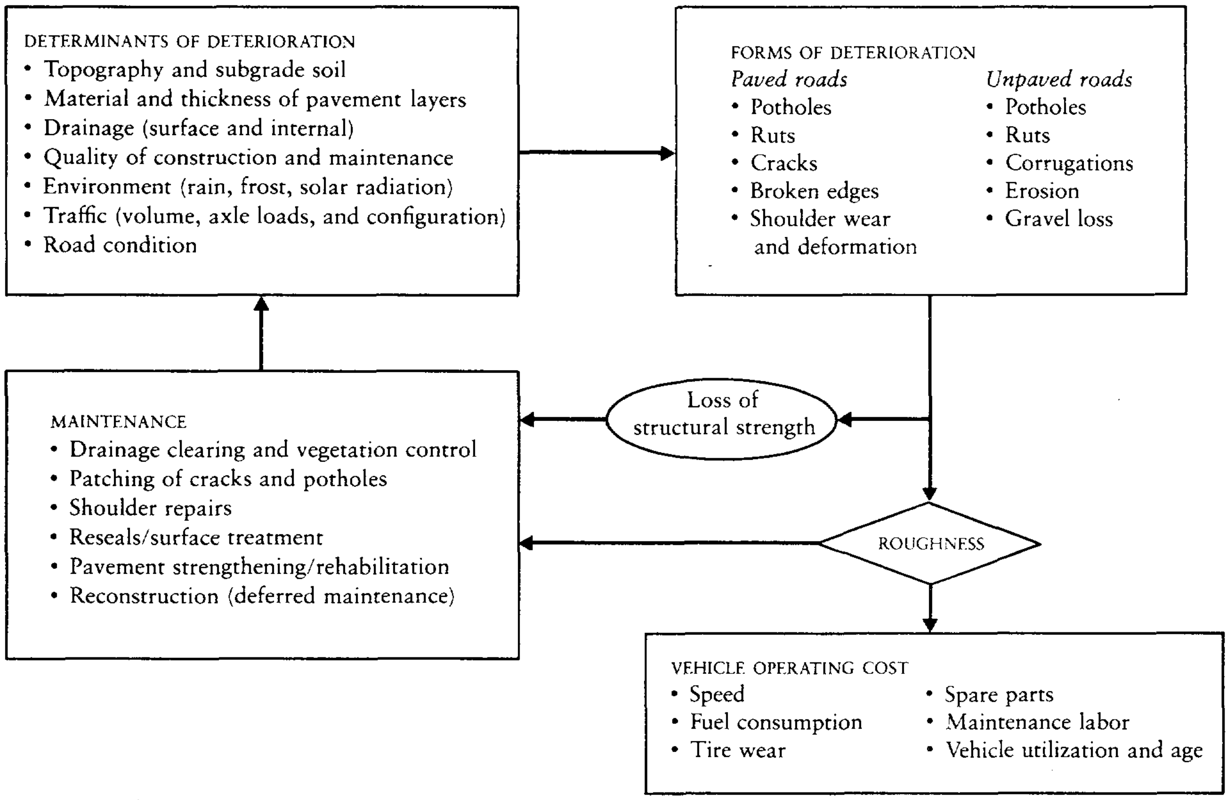
The Analytical Framework

The World Bank's Highway Design and Maintenance Standards Study (HDM) and the operational model developed from it (now in its third version, HDM-III) provide the framework for the technical analysis of the investment and maintenance options (Chesher and Harrison 1987; Paterson 1987; Watanatada, Dhareshwar, and Lima 1987; and Watanatada and others 1987). The model enables investigators to evaluate policies, standards, and programs of road construction and maintenance by applying the results of empirical research on the physical and economic relationships that underlie the deterioration of roads. The main variables in the road deterioration cycle and the general relations among them are shown schematically in box B-1. Most of these effects can be simulated with the model, which contains empirical relationships that have been statistically validated. Using data on existing roads and their condition and estimates of future traffic volume and composition, the model predicts the deterioration of roads and the effects of specified maintenance and improvement policies. It then estimates the cumulative effect of these processes on road condition, particularly road roughness (one of several such parameters estimated by the model), which has a significant effect on the cost of operating vehicles on the roads.

The model permits the evaluation of several maintenance alternatives for a road link, a group of roads with similar characteristics, or an entire network of paved and unpaved roads. It computes the aggregate costs of carrying out specified maintenance and construction policies, the associated vehicle operating costs, and the time streams of total life-cycle costs discounted at several rates to find net present values or internal rates of return. These criteria are used to determine optimal combinations of road design and maintenance policies. Maintenance policies under budget constraints are found by linking the HDM-III model to its companion Expenditure Budgeting Model, which employs dynamic programming to deal with multiperiod resource constraints.

Vehicle operating costs constitute a large share (75–95 percent) of the total cost of road transport, except when the traffic volume is extremely low. Thus the effect of even a small percentage change in vehicle operating costs is large relative to the effect of changes in construction and maintenance costs. Before the HDM studies, no empirical data on the relationship between vehicle operating costs and the *condition* of a road's surface (roughness) were available. Investment decisions were guided by imprecise and fragmentary estimates of such costs primarily in relation to the *type* of road surface (paved, gravel,

Box B-1. The Road Deterioration Cycle



Unpaved roads. If they are not maintained, unpaved roads deteriorate rapidly and reach very high levels of roughness. The progression of roughness, however, is essentially linear, and the consequences of poor maintenance become apparent immediately. The action of traffic causes corrugation and rutting and, when combined with rainfall, creates deeper ruts, potholes, and even gullies and washouts. Excessive water reduces the road's load-bearing capacity and as a result intensifies the effect of traffic and speeds up the process of deterioration. In very dry conditions, the evaporation of water weakens the bond within the surface material, which then disintegrates under traffic. As the fine binding particles turn to dust, the loose gravel left behind needs periodic replenishment. The wear and tear on roads by traffic is thus strongly influenced by climatic factors. Topography and road alignment are also significant factors, because erosion, vehicle cornering, and hill climbing tend to increase gravel displacement. The condition of gravel and earth roads is highly sensitive to the level and frequency of maintenance.

Paved roads. The progression of deterioration on paved roads follows a distinctly nonlinear path. During a long initial phase that lasts up to two-thirds of the life cycle, there is little discernible deterioration and maintenance needs are minimal. The next phase, however, is characterized by accelerating deterioration (primarily cracking and rutting), which leads to increased roughness and, in extreme cases, potholing. In the absence of extensive maintenance operations, this eventually leads to structural failure. Cracking reduces pavement strength, and poor drainage and inadequate shoulder maintenance exacerbate this effect by allowing rain to penetrate the cracks and weaken the underlying layers. Pavement damage caused by poor drainage is particularly pronounced in wet climates and in areas subject to freezing. In one case study, heavy rainfall (150 millimeters a month) reduced pavement life by about 30 percent (from fourteen years to ten) compared with light rainfall (20 millimeters a month). Pavement deterioration is critically influenced by traffic level and loading, with damage increasing exponentially with axle load; the damage, however, may be curtailed by increasing pavement strength in terms of its structural number ($\overline{SN}$). In the examples studied (pavements with an initial $\overline{SN}$ of 1.5 to 2.0, and 0.25 to 0.45 million standard axle loads a year), doubling the initial strength postponed the need for an overlay by ten to twelve years.

Table B-1. Vehicle Operating Cost Indexes for Paved and Gravel Roads by Vehicle Class

Vehicle class and road type	Source: de Weille (1966)[a]	AASHTO (1977)[b]	HDM, 1985[c]
Passenger car			
Paved	100	100	100
Gravel	126–33	108–63	108–26
Light truck			
Paved	100	100	100
Gravel	141–52	109–56	114–38
Heavy truck			
Paved	100	100	100
Gravel	140–70	112–58	117–46
Articulated truck			
Paved	100	100	100
Gravel	150–70	113–61	115–44

Notes: See bibliography for source details.
a. From de Weille (1966), table 11, pp. 28–29.
b. Based on Winfrey (1968), table A-44, p. 727.
c. Based on an application of HDM-III to Costa Rican data. Steady-state roughness on gravel roads ranged from 5.0 to 9.0 IRI.

earth). Based on improved estimates of vehicle speeds (in a free-flowing traffic regime) and operating costs, as a function of road design characteristics, the HDM research suggests that vehicle operating costs are somewhat less sensitive to changes in road condition than previously estimated. A comparison of the indexes of vehicle operating costs for paved and gravel roads shows significant differences between the HDM results and estimates from two earlier standard works (see table B-1).

Improvements in vehicle design over the past twenty years may in part account for the relatively lower estimates obtained from the HDM relationships. Nevertheless, certain road improvements may have smaller benefits (in vehicle operating costs saved) than previously estimated, and the inadequacy of past data may have contributed to the premature paving of lightly trafficked roads, particularly in Africa, and to the underdesign of heavily trafficked national roads in India, Indonesia, Nigeria, and Pakistan.

Case Studies

HDM-III and the Expenditure Budgeting Model were employed in a series of case studies to investigate optimal investment and maintenance policies under a variety of conditions. Road types and conditions, traffic, climate, and unit costs in the studies corresponded to those observed in three countries—Chile, Costa Rica, and Mali. The results, although specific to the circumstances studied in each country, were consistent enough to permit generalizations for wider application.

Thirty-one maintenance policy alternatives were tested for paved roads and ten for unpaved roads. The policies consisted of different maintenance packages with specifications of the deterioration levels at which they would be applied. The options for paved roads ranged from pothole patching, to bituminous resealing of the entire surface and more costly overlays of asphalt concrete, to major rehabilitation and reconstruction of the base and the surface (see the glossary at the front of this book for definitions of the various types of road improvement and maintenance works). A null case—comprising only those routine maintenance activities (drainage clearing, minimal vegetation control, and shoulder repair) included in all the other alternatives—served as a benchmark against which the costs of the alternatives were measured and compared. The alternatives are summarized in tables B-2 and B-3, where each is identified by a code (such as AL18). These codes are used throughout this appendix in discussing the results. Under policy AL18, for example, all potholes would be patched every year, a surface treatment would be applied whenever 25 percent of the area was visibly damaged, and a 40-millimeter overlay would be applied whenever roughness reached 5.0 on the International Roughness Index (IRI).

The roads in each country's network were grouped into broadly homogeneous classes according to sur-

Table B-2. Maintenance Policy Alternatives for Paved Roads

Alternative	*Patching (percentage of potholes patched annually)*	*Resealing*[a]	*Asphalt concrete overlay*		*Reconstruction*	
			40-millimeter	*80-millimeter*	*Bituminous surface treatment*	*Asphalt concrete*
AL00 (null)	0					
AL01	50					
AL02	100					
AL03	0				At 8.5 IRI	
AL04	50				At 8.5 IRI	
AL05	100				At 8.5 IRI	
AL06	100	At 75% damage				
AL07	100	At 50% damage				
AL08	100	At 25% damage				
AL09	100	At 75% damage			At 8.5 IRI	
AL10	100	At 50% damage			At 8.5 IRI	
AL11	100	At 25% damage			At 8.5 IRI	
AL12	100		At 5.0 IRI			
AL13	100		At 4.2 IRI			
AL14	100		At 3.5 IRI			
AL15	100		At 5.0 IRI	Immediate[b]		
AL16	100		At 4.2 IRI	Immediate[b]		
AL17	100		At 3.5 IRI	Immediate[b]		
AL18	100	At 25% damage	At 5.0 IRI			
AL19	100	At 50% damage	At 3.5 IRI			
AL20	100		At 5.0 IRI		Immediate[b]	
AL21	100		At 4.2 IRI		Immediate[b]	
AL22	100		At 3.5 IRI		Immediate[b]	
AL23	0					At 8.5 IRI
AL24	50					At 8.5 IRI
AL25	100					At 8.5 IRI
AL26	100	At 75% damage				At 8.5 IRI
AL27	100	At 50% damage				At 8.5 IRI
AL28	100	At 25% damage				At 8.5 IRI
AL29	100		At 5.0 IRI			Immediate[b]
AL30	100		At 4.2 IRI			Immediate[b]
AL31	100		At 3.5 IRI			Immediate[b]

Notes: Basic routine maintenance such as drainage clearing, minimal vegetation control, and repair of shoulders and drains is included in each alternative.

a. Resealing with bituminous surface treatment whenever the area of pavement surface with specific signs of distress and visible defects reaches the percentage shown.

b. During the first year of the period studied, followed by a maintenance strategy involving patching, reseals, and overlays at the intervals specified.

face type, condition in the initial year of the study, and traffic volume. For each class, road deterioration and maintenance activities over a thirty-year period were simulated under various maintenance alternatives. Maintenance costs and vehicle operating costs were computed, discounted to the initial year, and subtracted from costs for the null case. The results gave the net present value for each alternative relative to the null. From these results the best strategy for different levels of funding and discount rates was determined for each road class. With the aid of the Expenditure Budgeting Model, the results for different road classes were combined to find optimal network strategies, costs, and benefits under conditions involving no budget constraints and also under varying levels and time periods of overall budget constraints. The detailed results from the case studies were used to explore cost-effective road investment and maintenance options. The main findings have been grouped into the following topics for discussion:

- Selection of cost-effective maintenance policies

Table B-3. Maintenance Policy Alternatives for Unpaved Roads

Alternative	*Blading frequency*	*Spot regraveling*[a]	*Gravel resurfacing*[b]
AL00 (null)	None	No	No
AL01	Once a year	Yes	No
AL02	Every 8,000 vehicle passes	Yes	No
AL03	Every 6,000 vehicle passes	Yes	No
AL04	Every 4,000 vehicle passes	Yes	No
AL05	Every 2,000 vehicle passes	Yes	No
AL06	Once a year	Yes	Yes
AL07	Every 8,000 vehicle passes	Yes	Yes
AL08	Every 6,000 vehicle passes	Yes	Yes
AL09	Every 4,000 vehicle passes	Yes	Yes
AL10	Every 2,000 vehicle passes	Yes	Yes

Notes: Basic routine maintenance such as drainage clearing, minimal vegetation control, and repair of shoulders and drains is included in each alternative.

a. Replacement of 30 percent of total gravel loss each year.

b. Resurfacing with a gravel layer 150 millimeters thick whenever thickness of existing surface falls below 50 millimeters.

- Optimization of maintenance expenditures under budget constraints
- Criteria for choosing pavement strength
- Economic traffic thresholds for paving gravel roads
- The impact of overloading.

Selection of Cost-Effective Maintenance Policies

The choice and timing of maintenance operations on paved and unpaved roads are strongly affected by the differences in their deterioration characteristics. With unpaved roads, whose deterioration is both linear and rapid, special attention to routine maintenance is required, particularly with regard to the frequency of blading. With paved roads, the nonlinear path of their deterioration permits more options as to the choice and timing of maintenance.

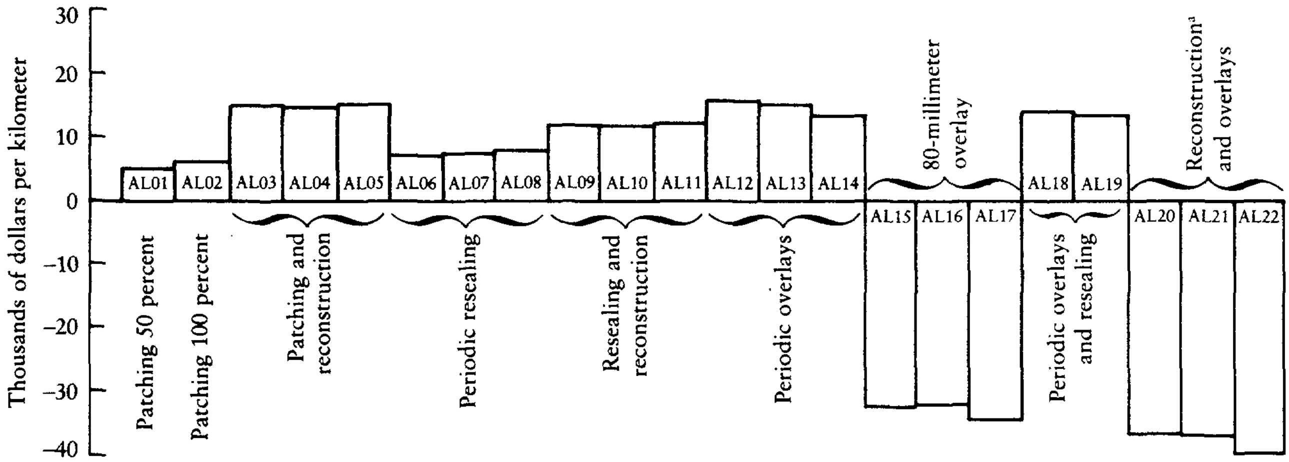
To identify cost-effective maintenance policies for paved roads, particularly under conditions involving budget constraints, the tradeoff between agency and user costs was examined. Figure B-1 shows the results of an analysis of twenty-two maintenance alternatives for a low-volume paved road in good to fair condition in Mali, with an average daily traffic of 400 vehicles. (Only twenty-two of the thirty-one alternatives specified in table B-2 are depicted because results for some pairs of alternatives were identical.) The top chart (A) shows the present value, discounted at 12 percent, of the net cost saving of each alternative relative to the null case. The net cost saving is determined by subtracting the increase in maintenance and construction costs incurred by the road agency from the difference in vehicle operating costs. In most cases this yields a positive saving, but alternatives AL15, AL16, and AL17 (involving the immediate application of a thick overlay) and AL20, AL21, and AL22 (involving immediate reconstruction) cost more than the benefits they yield when discounted at 12 percent.

Net present value, again discounted at 12 percent, is maximized by strategy AL12 (patching all potholes annually and applying a 40-millimeter overlay whenever pavement roughness exceeds 5.0 IRI). But several other alternatives, with very different combinations of vehicle operating costs and road agency expenditures, are almost as good by this measure. This finding is important because it widens the room for maneuver when agencies are subject to budget constraints. For example, the curve in graph B, which relates agency expenditures to vehicle operating costs for selected alternatives, shows that AL05 (pothole patching until roughness reaches 8.5 IRI, then reconstruction) entails about half the road agency expenditure of AL12, while vehicle operating costs are higher by about $1.10 for each agency dollar saved—a net loss of only $0.10 per $1.00 of reduction in agency expenditure. If funds are limited, this may be an attractive option.

The net present value of total transport costs for different levels of agency expenditures is illustrated in figure B-2 for four cases. The most efficient maintenance alternatives lie on the positively sloped segment of the outer boundary—the efficiency frontier. Alternatives represented by points inside the frontier are always inferior to a combination of maintenance options lying on the frontier. For example, in case A (Mali), AL09 has a net present value of $12,000 a

Figure B-1. Analysis of Maintenance Alternatives for a Low-Volume Paved Road in Good to Fair Condition (Mali)

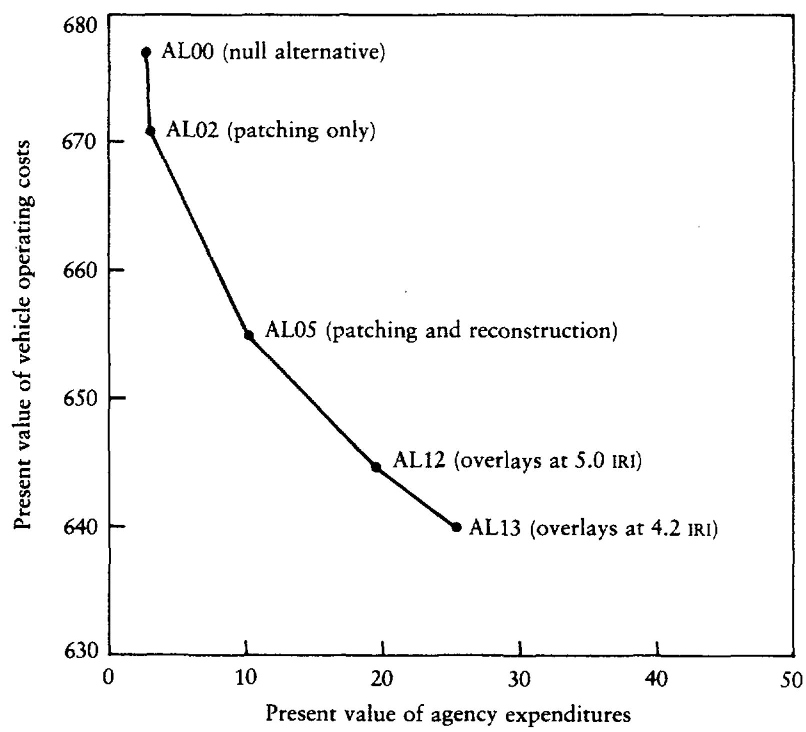
A. Net present value of maintenance alternatives



a. With bituminous surface treatment.

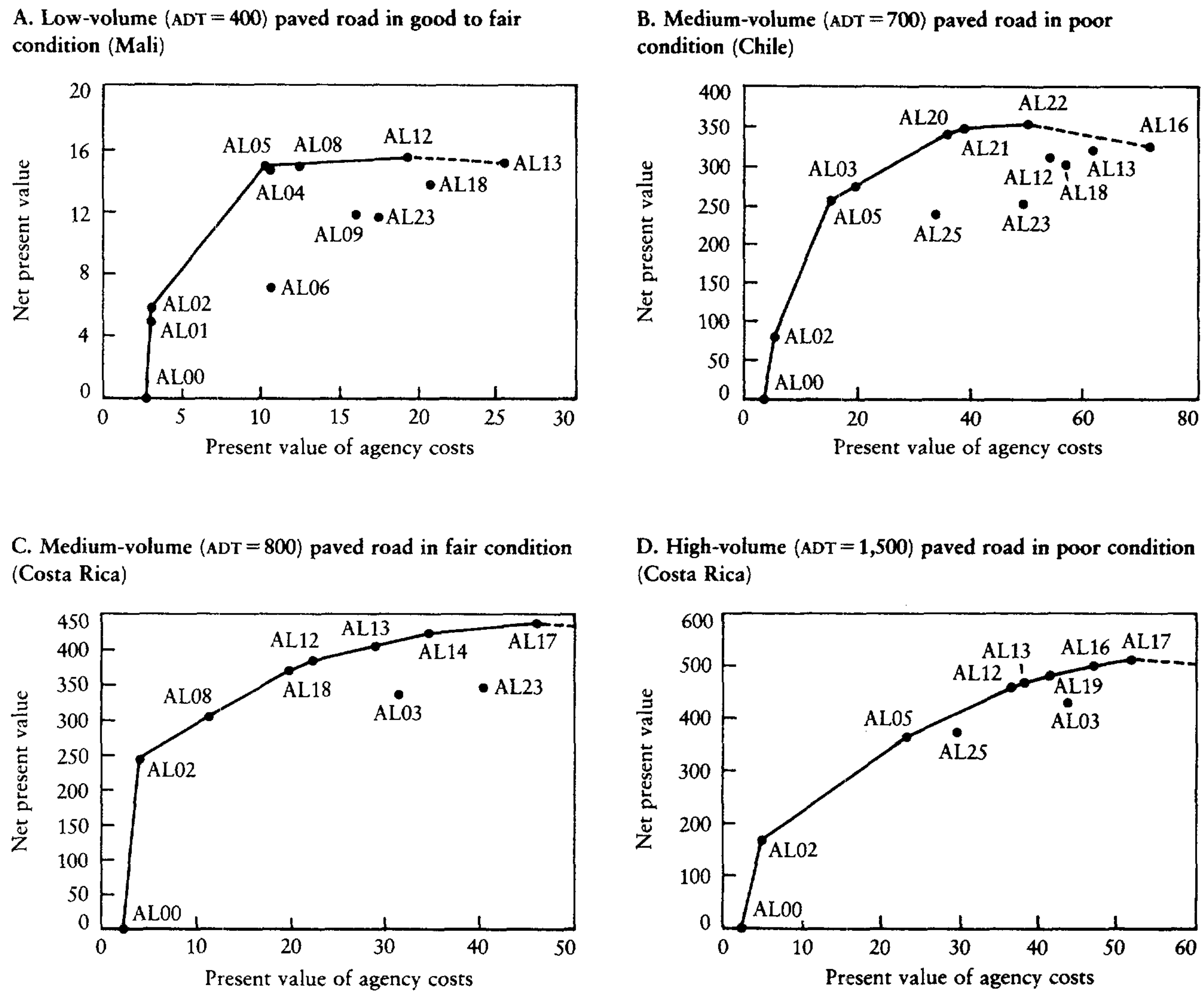
B. Vehicle operating costs versus road agency costs

(thousands of dollars per kilometer)



Note: See table B-2 for specifications of the maintenance alternatives.

Figure B-2. Net Present Value versus Road Agency Expenditures for Selected Maintenance Strategies
(thousands of dollars per kilometer)



Note: See table B-2 for specifications of the maintenance alternatives.

kilometer at a present value of agency cost of $15,800 a kilometer. A higher net present value can be obtained at the same agency cost by using AL05 on part of the road group and AL12 on the rest; the optimum maintenance strategy then lies on the line connecting AL05 and AL12 on the graph. In the absence of budget constraints, the alternative that maximizes net present value should be selected. Agency expenditures beyond this point (AL12) yield benefits that are less than the increased costs, as reflected by declining net present value.

The curve also shows the optimal order of retracting when agency resources are cut. The lower-order options are selected by successively reducing agency expenditures in ascending order of their marginal contribution to net present value. Where traffic is heavier, and especially where roads are initially in poor condition (cases B and D), the economic loss per dollar saved by the agency is considerably higher, and of course successive reductions in expenditure have increasingly costly consequences. The steepest slope of the efficiency frontier, indicating the severest penalty, is reached when the only expenditure available for cutting (always excepting minimal routine maintenance) is pavement patching.

A summary of the maintenance options recommended for paved roads, based on generalizations drawn from the case studies, is presented in table B-4. These recommendations reflect interactions between traffic levels and road conditions and the maintenance interventions needed to reduce the total cost of road transport. In individual cases the level and frequency of optimal maintenance actions may vary significantly from those recommended because of variations in construction and maintenance practices, traffic loading characteristics, environmental conditions, or factor costs. For example, the results of the case studies suggest that surface treatments become a viable economic alternative to asphalt overlays when the cost per kilometer for surface treatment drops to 25 percent or less of that for an overlay.

On unpaved roads the primary maintenance-related determinant of roughness—and so of the cost of operating vehicles—is the frequency of surface blading. Simulation and cost analysis of the effects of the various maintenance options (see table B-3) show that blading costs and vehicle operating costs are closely balanced over a wide range of blading frequencies. The optimal frequency is in the range of one blading every 4,000 to 8,000 vehicle passes, which is consistent with what is generally accepted as good practice (for example, one blading a month at 150–200 vehicles a day). Incremental increases in blading frequency within this range result in marginal reductions in user costs that are almost completely offset by corresponding increases in agency cost. Figure B-3 shows plots of net present value

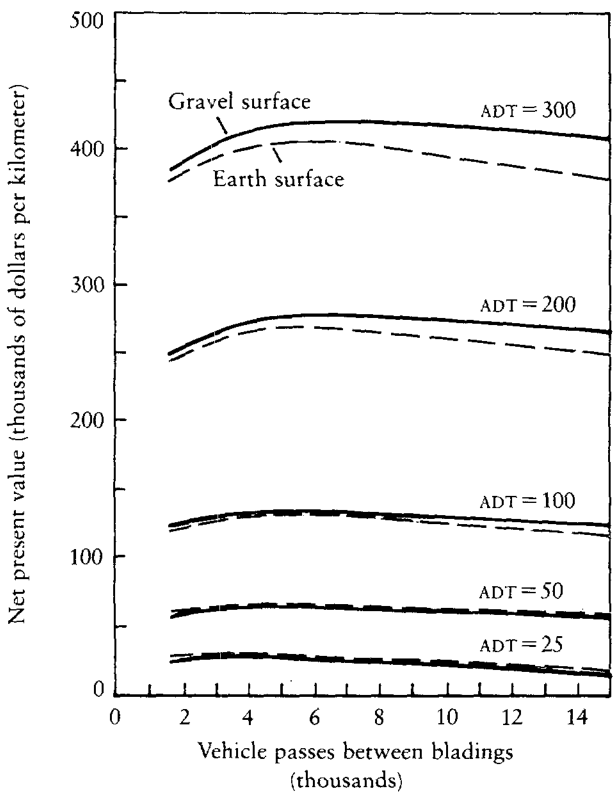
Table B-4. Recommended Maintenance Options for Minimizing Transport Costs on Paved Roads

Average daily traffic (number of vehicles)	*Initial road condition*[a]	*Recommended maintenance*
Fewer than 200	Good to poor	Pothole patching only until roughness level becomes very high (8.5 IRI) and the traffic volume has risen sufficiently (ADT > 200) to warrant pavement reconstruction.
200 to 500	Good to fair	Pothole patching and overlays (for example, 40-millimeter asphalt concrete whenever roughness reaches 4.2 to 5.0 IRI). Under budget constraints, surface treatments may be substituted for overlays.
	Poor	Immediate reconstruction of the pavement.[b]
500 to 1,000	Good	Pothole patching plus periodic overlays (40-millimeter asphalt concrete at 3.5 to 4.2 IRI).
	Fair	Same as above but with an initially thicker overlay (80-millimeter asphalt concrete) in cases of weak pavement.
	Poor	Immediate reconstruction of the pavement.[b]
1,000 to 2,000	Good to fair	Pothole patching plus periodic overlays (40-millimeter asphalt concrete at 3.5 IRI). Where the existing pavement is weak, the initial overlay should be thicker (80-millimeter). Periodic surface dressings are economical on strong pavements in good condition.
	Poor	Immediate reconstruction of the pavement.[b]
More than 2,000	Good	Pothole patching plus periodic surface dressings (when 25 percent of the area is damaged) in addition to periodic overlays (40-millimeter at 3.5 IRI).
	Fair	Pothole patching plus periodic overlays (40-millimeter asphalt concrete at 3.5 IRI). Where the existing pavement is weak, the initial overlay should be thicker (80-millimeter).
	Poor	Immediate reconstruction of the pavement.[b]

a. Good = less than 3.5 IRI; fair = 3.5 to 5.8 IRI; poor = greater than 5.8 IRI.

b. Some provision for patching and emergency maintenance should be made to keep the road serviceable during the reconstruction period.

Figure B-3. Variation of Net Present Value with Blading Frequency (Costa Rica)



versus blading frequency obtained from the Costa Rican study. Even at low traffic levels (twenty-five vehicles a day), the economic returns on blading are substantial. Blading once a year appears to be an acceptable minimum threshold. Although blading once after every 4,000 to 8,000 vehicle passes would be an optimal policy, less frequent blading does not occasion serious economic loss if the road is regraveled at appropriate intervals. Local conditions will strongly influence the maintenance options for unpaved roads. Extreme combinations of soils and climate (sands in arid climates, heavy clays in wet climates) may justify surfacing earth roads with gravel at an average daily traffic flow of fewer than fifty vehicles to ensure accessibility.

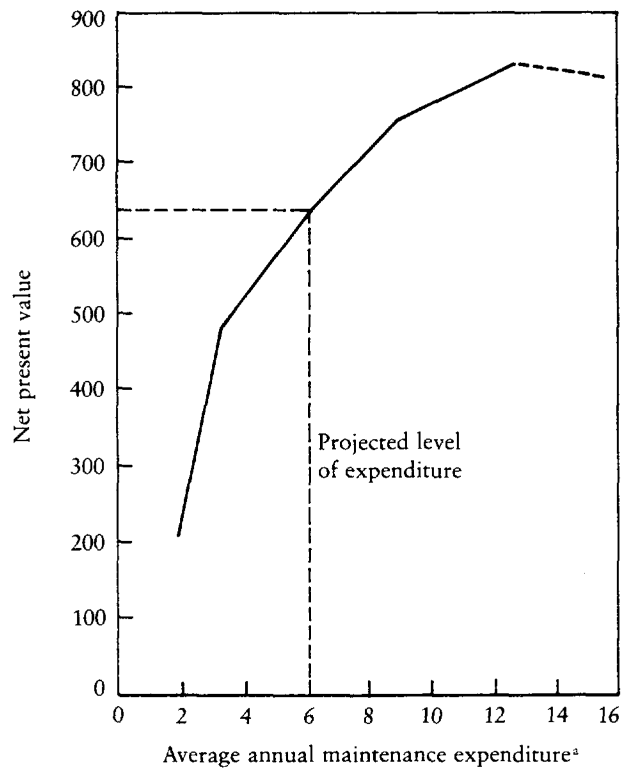
Where capital—especially foreign exchange—is scarce and unskilled labor is available at competitive rates (currently about five dollars or less a day), using labor-based work methods to perform spot repairs on gravel roads and simple drags attached to agricultural tractors or trucks to even out surface corrugations could prolong the time between bladings with mechanical graders. For unpaved roads with very low traffic volumes, the increased use of labor for spot repairs could offer a viable alternative to mechanical means of maintenance (Coukis and others 1983). The lower maintenance costs would offset the somewhat higher vehicle operating costs.

Optimization of Maintenance Expenditures under Budget Constraints

When the maintenance budget for a network is less than that required for the overall optimum, allocations to specific road classes (defined on the basis of design, traffic, and road condition and, where appropriate, further stratified by regional, climatic, or other relevant factors) must be reduced from their optimal levels. But maintenance expenditures should not be reduced uniformly across all road classes. The loss in net present value can be minimized by first reducing allocations to those roads for which the efficiency frontier is least steep. In general, candidates for cutting are maintenance operations with high unit costs on roads with low volumes of traffic and good existing surfaces. After the optimal activities have been completely replaced by the next-best options in a road class, the penalty for further cutbacks will be proportionately greater—the frontier will be steeper—and it may be economical to reduce allocations to some other road classes as well. Roads with very high volumes of traffic and poor surface conditions suffer the greatest loss in benefits for each dollar of reduction in maintenance outlay, and their allocations should be reduced last.

The effects of reductions in the maintenance budget on the choice of alternatives and on the resulting benefits were examined for the road networks of Chile, Costa Rica, and Mali. In Costa Rica the maximization of total net benefits would require spending an average of $12.5 million a year on maintenance for the first ten years, with $38 million needed in the first year alone to rehabilitate the paved roads in poor condition. Figure B-4 shows the maximum net present value of benefits (discounted at 12 percent a year) for the Costa Rican road network under different levels of average annual maintenance expenditures, optimally allocated among different classes of road. If the budget is raised from the presently planned level of $6 million a year to the optimal level of $12.5 million a year over twenty-five years (or by $51 million in present value), the attainable net present value (with the best use of the funds in both cases) increases by $200 million, from $635 million to $835 million. The optimal program, even

Figure B-4. Variation of Net Present Value of the Entire Road Network as a Function of Average Annual Maintenance Expenditures (Costa Rica)
(millions of dollars)



a. Ten-year average.

with unlimited funds, would not keep all roads in good condition. In Costa Rica it would provide for a high level of maintenance to keep two-thirds of the paved roads in good condition, with the other third to be maintained at lower standards.

For Chile the best maintenance strategy for the road network is similar to that for Costa Rica: two-thirds of the paved roads to be kept in good condition and the rest maintained at lower standards. The optimal program involves the immediate expenditure of large sums for the rehabilitation of paved roads and assigns high priority to such rehabilitation even if the budget has to be cut back. That is the course Chile actually adopted, and the planned budget for maintenance of all roads—$140 million a year during 1984–91—is approximately the amount required for the optimum derived in this study. If the budget were reduced for any reason, the losses would be large for this highly trafficked network.

In Mali, by contrast, where 84 percent of the paved roads carry fewer than 200 vehicles a day, only patching and basic routine maintenance is economically justified on most roads. The most economical option is to keep only about 1 percent of the paved network in good condition and maintain the rest of the network at considerably reduced standards, mainly with patching and routine maintenance on paved roads and minimal blading on unpaved roads. Even so, about $9 million is required to clear Mali's backlog of economically warranted rehabilitation projects for high-volume paved roads currently in poor condition. And the average annual expenditure required to maintain the combined network of paved and unpaved roads is estimated at $6.2 million a year—about twice the current expenditure. If expenditures were raised to $6.2 million ($24.3 million in present value over twenty-five years), the present value of the benefits is estimated at more than $46 million.

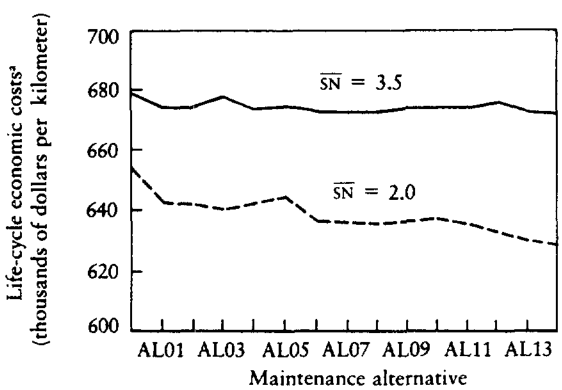
Maintenance activities are often deferred during periods of austerity. For unpaved roads, as long as basic routine maintenance is carried out regularly, the primary effect of deferring blading and, to a lesser extent, regraveling is to increase vehicle operating costs during the deferral period. The effect on subsequent road restoration costs is not large, unless the road is allowed to become so bad that it has to be reconstructed, generally on a new alignment. For paved roads, however, both effects can be important: vehicle operating costs increase during the deferral period, and the cost of pavement rehabilitation can vary substantially, depending on the stage in the deterioration process at which deferral occurs. On newly constructed or rehabilitated pavements with light axle loading, the effect of deferring maintenance (other than basic activities such as drainage) for one to five years is negligible. Once pavement condition becomes fair or poor, the impact is large.

Criteria for Choosing Pavement Strength

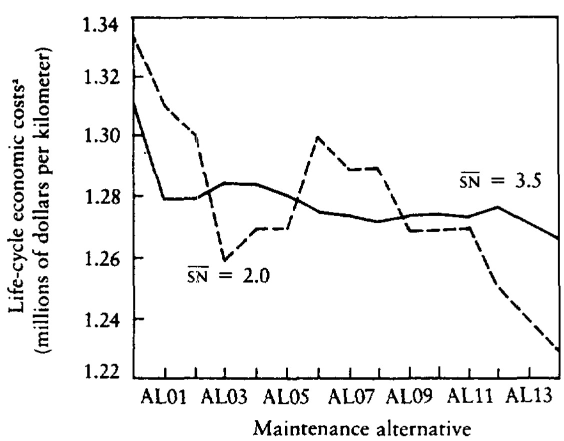
When a new pavement is constructed or an existing one replaced or overlayed, the choice of design strength should take account of the reliability of future maintenance. Low probabilities of adequate maintenance and timely strengthening in the future favor building a strong pavement initially, since stronger pavements enjoy a longer grace period during which maintenance needs are minimal. A normal full-strength pavement is defined as one designed to carry a specific number of cumulative equivalent

Figure B-5. Influence of Maintenance Policies on the Selection of Initial Pavement Strength

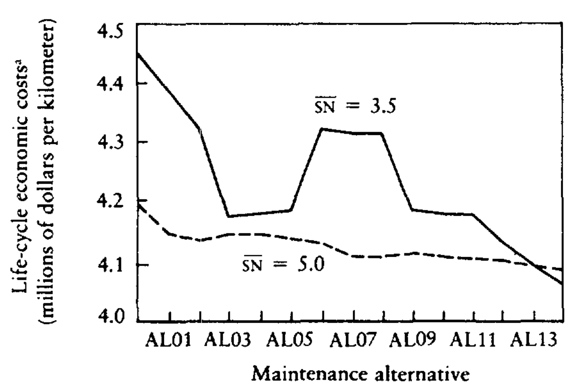
A. Light traffic (ADT = 500), lightly loaded (0.04 million ESAL per year per lane)



B. Medium traffic (ADT = 1,000), lightly loaded (0.08 million ESAL per year per lane)



C. Heavy traffic (ADT = 2,500), heavily loaded (1.21 million ESAL per year per lane)



Notes: See table B-2 for specifications of the maintenance alternatives.
a. Present value discounted at 12 percent a year.

standard axle loads (ESAL) for a given level of pavement serviceability. To compensate for inadequate maintenance, a pavement strength higher than that given by normal designs may be warranted in certain situations. High probabilities of good maintenance will favor time-staging—that is, economizing on today's pavement and strengthening the road subsequently as needed. At the network level, time-staging is effective only if the condition of pavements is regularly monitored and evaluated. Without an appropriate pavement management system, it is difficult to predict the critical points in the pavement life when a major maintenance intervention may be needed to prevent premature structural failure.

To justify the time-staging of road construction, a minimum probability of adequate future maintenance is required. To estimate this threshold probability, life-cycle costs for pavements, with an initial structural number ($\overline{SN}$) of 2.0, 3.5, and 5.0, were estimated for a range of traffic volumes and axle loadings in Costa Rica (light) and Mali (heavy). Three of the cases are illustrated in figure B-5. Each case shows life-cycle costs (discounted at 12 percent) for the first fourteen of the thirty-one maintenance alternatives for paved roads specified in table B-2. In case A, with an average daily traffic (ADT) of only 500 vehicles and light axle loading, it would suffice to use a normal design ($\overline{SN}$ = 2.0) commensurate with the estimated ESAL, since the life-cycle costs are consistently higher for a higher-strength compensating design ($\overline{SN}$ = 3.5) under all maintenance assumptions. But with heavier traffic a different conclusion emerges, as shown by case C (ADT = 2,500 and heavy axle loading). In this case a normal full-strength pavement ($\overline{SN}$ = 5.0) will have a lower life-cycle cost, under almost any assumption about future maintenance, than a pavement with a lower initial strength ($\overline{SN}$ = 3.5), which represents the time-staging option. At or above this combination of traffic and axle loadings it would not pay to consider the time-staging option.

Between these two limits, the decision for or against the time-staging of construction is reached by balancing the loss that the lack of future maintenance could occasion against the cost saving from time-staging that would be realized if future maintenance (including strengthening) were performed as desired. In this way a threshold probability of performing good maintenance in the future is obtained; above this threshold the time-staging option could be justified. For case B in figure B-5, for example, with an ADT of 1,000 vehicles and light axle loads, the threshold probability was estimated at 33 percent as follows:

If

$x =$ probability of optimal maintenance (AL14)

$1 - x =$ probability of nil maintenance (AL00)

$D_{opt} =$ difference in life-cycle costs for initial pavement design strength of $\overline{SN} = 3.5$ and $\overline{SN} = 2.0$, under AL14

$D_{nil} =$ difference in life-cycle costs for initial pavement design strength of $\overline{SN} = 2.0$ and $\overline{SN} = 3.5$, under AL00

Then, from the inequality:

$$(D_{opt})\ (x) > (D_{nil})\ (1-x)$$

or $$(1.27 - 1.23)\ (x) > (1.33 - 1.31)\ (1-x)$$

Therefore, $x > 0.33$.

In this case the time-staging of pavement construction should be considered only if there is a one-third or better chance that good maintenance will be performed in the future.

Under funding arrangements that favor construction over maintenance or in situations in which external aid agencies are willing to finance construction but not maintenance expenditures, it is often expedient to forgo maintenance until it becomes necessary to reconstruct the pavement. AL03 in case B codifies such a maintenance strategy, an option that would also reduce life-cycle costs significantly if there is a fair expectation that funds for reconstruction will be forthcoming when needed. In this case a less than full-strength design could be considered for initial construction if the probability of obtaining future funds for reconstruction is 45 percent or better.

Table B-5 illustrates how the decision may vary in a wider array of cases. It maps out combinations of discount rate, daily traffic, and axle loadings in which the decision for or against time-staging is independent of the degree of uncertainty about future maintenance. In a middle area, however, the reliability of future maintenance matters. Time-staging is thus generally to be preferred if the probability of adequate maintenance in the future exceeds 30 or 75 percent, depending on traffic volumes and axle loads. At higher discount rates (in this case 24 percent), time-staging tends to be the preferred choice even with high traffic volumes, heavy axle loadings, and a relatively low probability of future maintenance.

Table B-5. Criteria for Selecting Time-Staged Pavement Design

Average daily traffic (number of vehicles)	*Axle loading*[a]	*Minimum probability of adequate maintenance required for time-staging option*[b] *At a discount rate of 6%*	*At a discount rate of 12%*	*At a discount rate of 24%*
300	Light	■	■	■
	Heavy	30%	■	■
500	Light	30%	■	■
	Heavy	n.a.	75%	■
1,000	Light	95%	30%	■
	Heavy	n.a.	80%	■
2,000	Light	95%	80%	15%
	Heavy	●	90%	15%
2,500	Light	●	95%	50%
	Heavy	●	●	60%

Notes: The economic costs for paving (in thousands of dollars per kilometer in 1984 prices), assuming all earthworks and structures already in place, were estimated as:

$\overline{SN}$	Costa Rica	Mali
2.0	19.6	27.2
3.5	68.5	59.3
5.0	118.8	129.4

a. Light axle loading is representative of conditions in Costa Rica (0.05–0.10 million ESAL per year per lane); heavy axle loading is representative of conditions in Mali (1.2 million ESAL per year per lane).

b. Time-staging of pavement construction is conditional on a minimum probability of adequate maintenance in the future. If the probability of adequate maintenance is below this level, a normal full-strength design should be used.

■ Compensatory design not applicable; low- to medium-strength pavements ($\overline{SN} < 3.5$ based on normal design) adequate for this level of traffic volume and loading.

● Time-staging not applicable; high-strength pavements ($\overline{SN} > 4.0$ based on normal full-strength design) appropriate.

n.a. Time-staging option not applicable; use normal-strength design.

Where capital is cheap or a greater weight is attached to long-term benefits (an intergenerational issue), stronger initial pavements based on normal design generally dominate (say, at a discount rate of 6 percent).

Economic Traffic Thresholds for Paving Gravel Roads

Even with the best maintenance practice, vehicle operating costs on gravel roads are between 10 and 30 percent higher than on paved roads. In addition, the present value of the cost of routine maintenance and resurfacing is between five and eight times greater for a well-maintained, high-volume gravel road than for a newly built paved road. Paving is therefore indicated when the expected savings in vehicle operating and maintenance costs (relative to a well-maintained gravel road) exceed the present value of the paving cost.

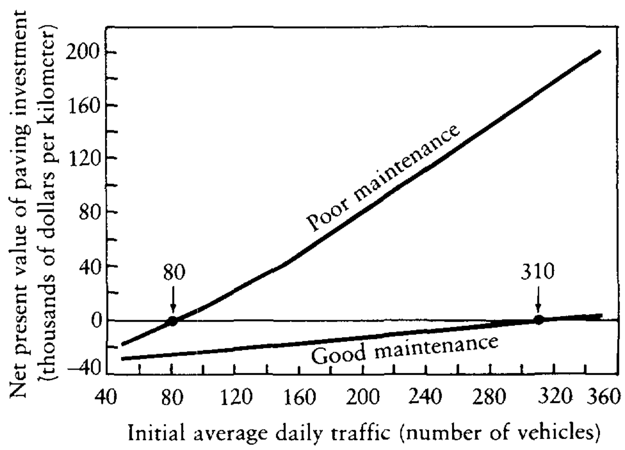
These cost tradeoffs seem to cover a wider range of traffic volumes than had commonly been assumed. Applications of HDM-III in Costa Rica and Mali indicate that the break-even traffic volume for paving may vary from less than 100 vehicles a day to more than 400, depending on the costs of paving, the discount rate, the rate of growth of traffic, and the anticipated quality of future maintenance.

Paving thresholds are also sensitive to variations in assumptions about the quality of maintenance. Where experience shows that the probability of adequate future maintenance is low, the traffic threshold for paving is lowered. And if there are no budget constraints, a case can be made for an all-weather paved road. Such roads may not require major maintenance work for as long as seven to ten years. With regard to total life-cycle costs, however, more frequent regraveling and grading operations carried out efficiently are likely to prove more economical than paving, particularly if the future availability of maintenance funding is uncertain.

The effect of quality of maintenance on paving thresholds is illustrated in figure B-6, which compares two maintenance regimes in Mali.

- *Good maintenance.* For the paved alternative: 100 percent patching and resealing every seven years. For the existing gravel road: grading every 4,000 vehicle passes and regraveling whenever gravel thickness falls below 6 centimeters.
- *Poor maintenance.* For the paved alternative: no patching or resealing, but reconstruction whenever roughness exceeds 12.0 IRI. For the existing gravel road: infrequent grading (about once a year) and no regraveling.

Figure B-6. Break-even Traffic Volumes for Paving a Gravel Road under Good and Poor Maintenance



It was assumed that the same level of basic routine maintenance (vegetation control, drainage clearing, and so on) would be performed in all cases. With good maintenance, the economic threshold for paving a gravel road occurs at a traffic level of 310 vehicles a day. With poor maintenance, however, the break-even traffic volume for paving is lowered to 80 vehicles a day. Inadequate maintenance increases the economic and political pressures on a road agency to make larger public investments in paving gravel roads which, had they been well maintained, would have continued to provide a reasonable level of service.

Paving gravel roads in arid zones is sometimes suggested as a way of alleviating the discomfort and inconvenience of travel on dusty roads, but it is difficult to quantity these benefits. Common observation suggests that vehicle speeds and passing opportunities on such roads are severely restricted by reduced visibility. The result is a traffic hazard similar to fog and congestion and akin to that caused by heavily loaded slow-moving vehicles on narrow roads. Not enough empirical information is available on traffic flow and vehicle operating characteristics in a dusty environment to evaluate the benefits of paving roads in arid or desert areas.

Lower paving thresholds may also be indicated for roads located in river deltas (in lower Bangladesh, for example), old lake beds, sandy deserts, or low coastal areas, because of the scarcity of gravel deposits and other sources of aggregate. In mountainous terrain, where maintenance costs may be excessive owing to the erosion caused by rapid runoff and the frequent need to replace gravel, it may make economic sense to protect the road with a bituminous surface. A technical alternative to using a gravel surface in these situations is to stabilize the existing soils with small amounts of a suitable binder (bitumen, cement, lime, or fly ash) and then apply a light bituminous seal, where necessary, to protect the stabilized material from the elements and traffic.

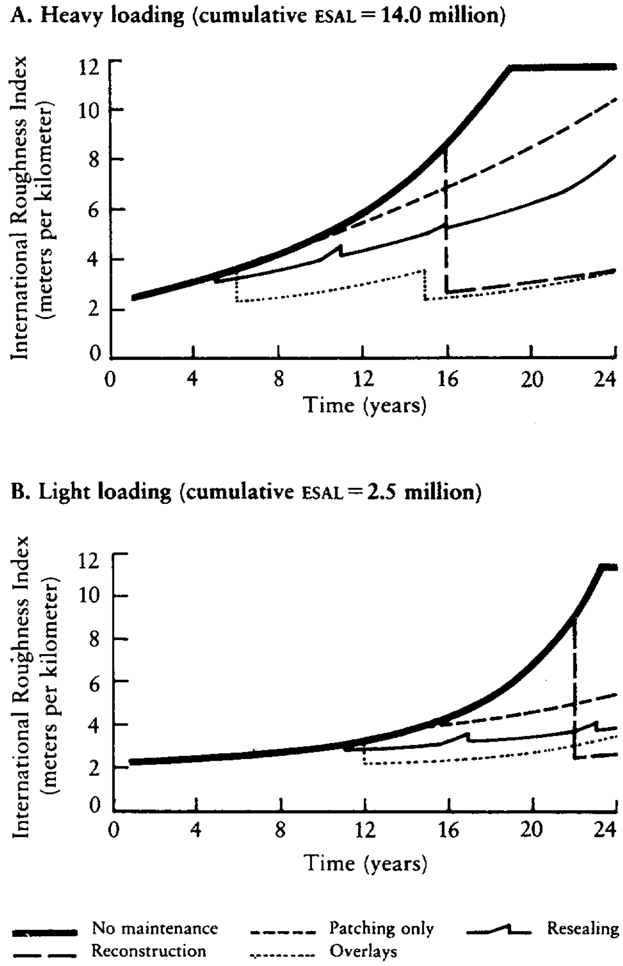
The Impact of Overloading

The onerous impact of overloading on pavement performance is reflected in the progression of roughness over time, given different maintenance policies and loading conditions on otherwise similar pavements (see figure B-7). Case A is typical of Mali, where trucks with heavy axle loads constitute 33 percent of the traffic and the cumulative ESAL per lane over twenty-five years is estimated at 14 million. Case B is typical of Costa Rica, where trucks with relatively light axle loads constitute 25 percent of the traffic and the cumulative ESAL per lane over twenty-five years is estimated at 2.5 million. The actual axle loads, on average, are about 60 percent heavier in case A, partly because of the higher axle load limits (thirteen-ton single axle) in Mali and partly because of overloading. Heavy loading significantly accelerates the rate of deterioration, and in this comparison the need for overlays in case A is advanced by some six years. Even with optimal maintenance, the average life-cycle roughness remains higher with heavier axle loads. The results for case A are typical of what has happened to pavements designed on the basis of an unrealistic assumption that axle load limits would be enforced.

Although empirical evidence shows that a significant part of pavement damage increases with the fourth power of the axle load, the regulation of axle loads has proved exceedingly difficult. Many road authorities have therefore built stronger and more expensive pavements, based on actual pavement loading, than would have been necessary with adequate control of axle loads. Expected changes in road transport technology resulting from road improvements (such as the introduction of combination vehicles in place of single-unit trucks) should be taken into consideration when pavements are designed.

Research on the economic optimum for axle loads suggests that limits in the longer term should be increased beyond the prevailing eight- to ten-ton single (and thirteen- to sixteen-ton tandem) axle loads; the economic gain from lower unit transport costs outweighs the loss in increased road damage. In the short term, however, the existing roads and bridges are not strong enough to carry heavier loads. Any increase in axle load limits should therefore be accompanied by a comprehensive plan for strengthening bridges and pavements.

Figure B-7. Effect of Traffic Loading on Pavement Performance



Note: Data are based on the following assumptions: $\overline{SN} = 3.0$ and ADT = 800.

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