Defining Optimum Policies for Maintenance of State Highway Networks in Brazil

Gerard Liautaud, Rodrigo Archondo-Callao, and Asif Faiz,
The World Bank

In low-income states such as those located in the northeastern part of Brazil, highway authorities require methodologies and analytical tools that enable them to allocate and spend the limited resources available for road maintenance activities as efficiently as possible. The framework and results are described of an analysis to define, under budgetary constraints, the most cost-effective strategies for the maintenance and upgrading of the highway networks in three neighboring Brazilian states: Maranhão, Piaui, and Tocantins in northeastern Brazil. Part 1 describes the general environment in the states, Part 2 outlines the proposed rehabilitation program and its various components, Part 3 presents the data (network and traffic surveys and vehicle and maintenance unit costs) on the basis of which the optimum maintenance strategies for both the paved and unpaved network were formulated and features the new HDM Manager developed by the World Bank to perform the economic analyses for various alternative strategies, and Part 4 develops and comments upon the results. In the conclusion, the procedures set out to monitor the performance and quality of the maintenance work program, as well as the indicators and targets defined for that purpose, are outlined.

In low-income states such as those located in the northeastern part of Brazil, highway authorities require methodologies and analytical tools that enable them to allocate and spend the limited resources available for road maintenance activities as efficiently as possible. This paper describes the framework and results of an analysis to define, under budgetary constraints, the most cost-effective strategies for the maintenance and upgrading of the highway networks in three neighboring Brazilian states: Maranhão, Piaui, and Tocantins in northeastern Brazil.

ENVIRONMENT

Geographical Setting

The neighboring states of Maranhão, Piaui, and Tocantins form a homogeneous subregion of an area of about 865 000 km^2 lying in the northeast and west central regions of Brazil. It is a zone of transition between the semiarid *sertao* of the northeast to the east, the humid low plains of eastern Amazonia to the west, and the high plains of the *cerrados* to the south. Figure 1 shows the location of these three Brazilian states.

Physical Features

All three states are approximately the same size, with an area between 250 000 and 325,000 km^2. They con-

FIGURE 1 Location of states in study.

sist essentially of plains and plateaus with altitudes generally ranging between 100 and 1000 m. The climate is either tropical (Maranhão and Tocantins) and therefore hot and humid, with a period of heavy rainfall extending from November to May, or semiarid to semihumid (Piaui). Annual rainfall normally ranges between 600 and 2,000 mm, with average temperatures between 24 and 28°C. Except in the northwest of Maranhão, where tropical forest is predominant, the vegetation consists by and large of savannah, dry bush, or native babassu palm. All three states have important rivers and abundant aquifers that give rise to considerable potential for irrigation. Ferralitic and residual soils are predominant and roadbed materials generally consist of sandy silts or reddish lateritic sandy clays with soaked California bearing rates (CBR) values usually ranging from 6 to 15. In all three states, lateritic or terrace gravel is available and generally used without a need for cement stabilization in subbase and base-course construction. Whenever rock materials are within a reasonable distance of road construction sites, double surface dressings are used for paving wearing courses; otherwise, sand asphalt carpets are common practice, particularly in Maranhão.

Economy

The three states are among the lowest-income states of Brazil, with per capita income of about $1,000 U.S. (compared with an average of $2,600 for Brazil). Total annual revenues range between $265 million and $500 million equivalent, grossly generated from value-added taxes and general transfers from the states' participation funds. The states' economy is largely dominated by cattle farming and agriculture, the main crops being rice, maize, soybeans, cassava, banana, and cotton. The development prospects in all three states are, however, encouraging as the combination of a number of factors, particularly the excellent compatibility between climatic or soil conditions and new soja varieties, is making the subregion grain production very competitive on international markets.

Condition of the Road Network

Although the state governments have been allocating between $25 million and $75 million to the road subsector each year, that is, from 10 to 20 percent of their total revenues, the road infrastructure is among the least developed in the country (between 5 and 20 km of roads per 100 km^2 of land, including federal and municipal roads).

The total length of the networks under the jurisdiction of the states is on the order of 20 650 km, each state being responsible for between 5000 and 8000 km (excluding federal and municipal roads). Approximately 19 percent of the aggregated network is paved, 60 percent is graveled, and the remaining 21 percent consists of earth roads. Typical pavement construction consists of a lateritic gravel base course overlain by either a 4-cm-thick sand-asphalt carpet or a double surface treatment.

Maintenance conditions vary significantly as a function of pavement surfacing type. On the paved network, visual surveys show that 32 percent of the network is in good condition, 42 percent in fair condition, and 26 percent in poor condition. On the unpaved network, only 16 percent of the network is in good condition, whereas 62 and 22 percent are, respectively, in average and bad condition.

The above figures suggest that these states are confronting a threefold problem of maintenance, paving, and extension of their road network (*1–3*).

State Road Agencies

To administer and manage the road network, each state has a road department that generally comprises three divisions: studies and planning, new construction, and maintenance. Activities in the field are carried out or supervised by some 7 to 12 road districts, each one responsible for about 500 to 1000 km of roads. Although, the road departments employ some 800 to 1,000 civil servants, thus representing a fair ratio of some 14 employees per 100 km of roads. However, equipment is scarce, amounting to about 150 to 200 units per state, which suggests that the states' own ability to undertake maintenance work by force account meets only 15 to 30 percent of total needs, hence the necessity to call upon maintenance by private contracts.

Proposed Rehabilitation Program

In order to restore and further maintain an adequate level of service over their road network, the three state governments are taking the necessary measures to implement the following strategies:

- Rehabilitation or resurfacing over a period of about 3 to 5 years of all sections of the paved network that currently exhibit signs of fatigue or deterioration;
- Adequate routine maintenance on the total length of both the paved and unpaved network; and
- Upgrading and paving of the portion of the network where total transport costs have become excessive as a result of traffic volume, expensive grading and regraveling operations, or both.

Consequently, an overall 5-year program was designed consisting of three similar subprojects, each one including (*a*) a rehabilitation and resurfacing component covering approximately 1550 km of paved roads in bad or critical condition, (*b*) a maintenance component covering some 4000 to 5000 km of paved roads and 15 000 km of unpaved roads, and (*c*) a paving component consisting of the highest-priority upgrading and asphalt-surfacing of approximately 2600 km of currently unpaved roads. In order to strengthen the planning system and monitoring capacity of the state road agencies, a policy and institutional development component, including technical assistance and training provided by qualified consultants, has been integrated in the rehabilitation program.

Design of Optimum Maintenance Strategy

Data

Over the last 3 to 5 years, major emphasis has been placed upon upgrading or new construction, and scant resources have remained available for maintenance operations: annual maintenance budgets ranged between $700 and $1,500 per km, which is substantially below the optimum level. In order to define a more reasonable level of expenditures to be allocated to the maintenance of both the paved and unpaved network in each state, the HDM-III model and the more recent HDM Manager program, both developed by the World Bank, were used to perform the economic evaluation of a set of maintenance strategies. As presented in more detail later, the program computes the road deterioration and the total transport cost streams (road agency and vehicle operating costs) for each of the strategies being evaluated, as well as the economic indicators [net present value (NPV) or internal rate of return (IRR)] used to compare these strategies against a base strategy (generally a "do-nothing" or a "do-minimum" strategy).

In order to operate the program, the following information is required:

- Current characteristics of the network and its environment,
- Traffic volumes,
- Vehicle fleet data and vehicle operating costs, and
- Maintenance operations unit costs.

These data are summarized below.

Network Characteristics

For each state and in view of the relative uniformity of climate, topography, material resources, and road geometrical standards, average representative values of rise and fall, horizontal curvature, pavement width and composition, precipitation, and altitude have been assumed, if one considers the whole network as consisting of two homogeneous links: one unpaved and one paved. Table 1 summarizes the features of each of these links.

Traffic Volumes

Table 2 presents distribution of traffic volume on the paved and unpaved networks. By and large, the proportion of commercial vehicles ranges from 25 to 50 percent (35 percent on average), and overloading with respect to the maximum legal single-axle load of 11 tons is not uncommon.

Vehicle Fleet Data and Operating Costs

Table 3 gives average values of parameters used in the calculation of vehicle operating costs. When a representative vehicle distribution pattern as shown in Table 3 and average topographical conditions as given in Table 1 are taken into account, the aggregated vehicle operating cost per vehicle kilometer can be expressed by the following formula:

$$VOC = 0.182 \exp 0.0686 IRI$$

where VOC is the average vehicle operating cost per km in U.S. dollars and IRI is the international roughness index in meters per kilometer.

TABLE 1 Network Characteristics: Average Representative Values

Characteristics	Paved network	Unpaved network
Carriageway width (m)	6	7
Shoulder width (m)	1	n.a.
Altitude (m)	150	300
Rainfall (m/month)	0.12	0.12
Rise + Fall (m/km)	16	18
Curvature (degree/km)	23	20
Modified Structural Number	2.8	n.a.
Current av. roughness IRI m/km	4 to 5	12
Gravel properties (unpaved road)		
Max. particle size (mm)	n.a.	25
% < 2 mm	n.a.	58
% < 0.425 mm	n.a.	52
% < 0.075 mm	n.a.	22
Plasticity Index	n.a.	<10

TABLE 2 Traffic Volume Distribution on Network

Average daily traffic	Percentage distribution	
	Unpaved network	Paved network
< 25	42%	0%
25-50	23%	0%
50-100	19%	0%
100-300	16%	47%
300-500	0%	45%
500-1000	0%	8%
> 1000	0%	0%

Maintenance Operations Unit Costs

Table 4 presents the financial unit costs for typical maintenance operations for both the paved and unpaved networks. Economic costs generally represent 80 to 87 percent of the financial costs.

HDM Manager Computer Program

HDM Manager (4–7) is a "front-end and back-end" shell program for the World Bank's Highway Design and Maintenance Standards Model (HDM-III), a computer model for analyzing the total transport costs of alternative road improvement and maintenance strategies. HDM-III provides detailed modeling of pavement deterioration and maintenance effects and calculates annual costs of road construction, maintenance, and vehicle operation. Accidents and other impacts can be added exogenously to the economic evaluation. HDM-III is widely used in the evaluation of specific road proposals, national or regional road investment analyses, and road maintenance policy assessments.

HDM Manager is a user-friendly HDM-III shell environment. It stores the input data efficiently, creates all the required HDM-III input files, runs the HDM-III program, collects the results, and presents them in a practical way. The program is a simple but powerful package for learning and using the major features of HDM-III. HDM Manager is designed for use with the full HDM-III software package and documentation, which must be obtained separately.

HDM Manager is designed to evaluate a set of road agency strategies applied to paved or unpaved roads. The program computes the road deterioration, the cost streams (road construction, maintenance, vehicle operation, and total society costs) for each of the road

TABLE 3 Typical Fleet Parameters

Parameters	Cars	Pickup	Bus	Light truck	Med. Truck	Heavy Truck	Arti-culat.
% distribution	31	16	6	16	18	11	2
Gross veh. wgth (t)	1.05	1.33	7.6	2.1	5.1	8.2	18.3
Number of axles	2	2	2	2	2	3	5
Number of tyres	4	4	6	4	6	10	18
ESAL factor/veh.	0.00	0.01	1.2	0.3	2.6	6.1	12
Number of passengers	1	1	17	1	1	1	1
Service life (years)	13	13	13	14	15	15	12
Hours driven/yr	830	1033	2560	1500	1660	2650	3000
Km driven/yr (*1000)	42	50	102	52	68	93	130
Annual interest rate	12%	12%	12%	12%	12%	12%	12%
Economic unit costs US$							
New vehicle price (*1000)	8.68	8.33	101.6	13.5	53.0	65.0	102.0
New tyre price	43	47	226	200	218	240	300
Maintenance labor/hr	2.23	2.23	2.23	2.23	2.23	2.23	2.23
Time/veh-hr	0	0	3.29	2.32	2.32	2.32	2.81
Gas price/liter	0.35	0.35	n.a.	n.a.	n.a.	n.a.	n.a.
Diesel price/liter	n.a.	n.a.	0.21	0.21	0.21	0.21	0.21
Lubricant price/lit.	2.8	2.8	2.8	2.8	2.8	2.8	2.8

TABLE 4 Average Maintenance Unit Costs

Maintenance operations	Financial cost US$
Grading ($ per km)	230
Gravel resurfacing ($ per cu. m)	4.4
Unpaved routine maintenance ($/km-yr)	880
Patching ($ per sq m)	6
Reseal 20 mm ($ per sq m)	1.3
Overlay 40 mm ($ per sq m)	5.3
Paved routine maintenance ($/km-yr)	1380

agency strategies being evaluated, and the economic indicators (NPV and IRR) used to compare the set of road agency strategies. After examining the results of the economic evaluation, the user selects the road agency strategy to be carried out, and the HDM Manager produces a project summary report with all the indicators needed to justify the project.

HDM Manager incorporates most but not all the features of HDM-III and has some constraints on parameter choices; for example, it works with seven vehicle types, whereas HDM-III works with 10. The main HDM-III features not included in the HDM-III Manager are the following: (*a*) division of links into sections and subdivision of sections into three subsections; (*b*) automatic execution of more than one link at a time; (*c*) definition of exogenous costs and benefits; and (*d*) use of alternative vehicle operating cost relationships.

To use HDM Manager, the user first installs HDM-III following the instructions given by the HDM-PC manual. After installing and running the HDM Manager, it displays the main menu shown in Figure 2. The main menu shows the basic structure of the program and presents a series of options (such as Analysis Control, Strategies, and Deterioration). For a basic economic evaluation of road agency strategies applied to a paved or unpaved road, users follow the steps described below:

- Step 1—Define the Analysis Control. Enter the discount rate, the analysis period, the calendar year of the initial year, and the currency to be used.

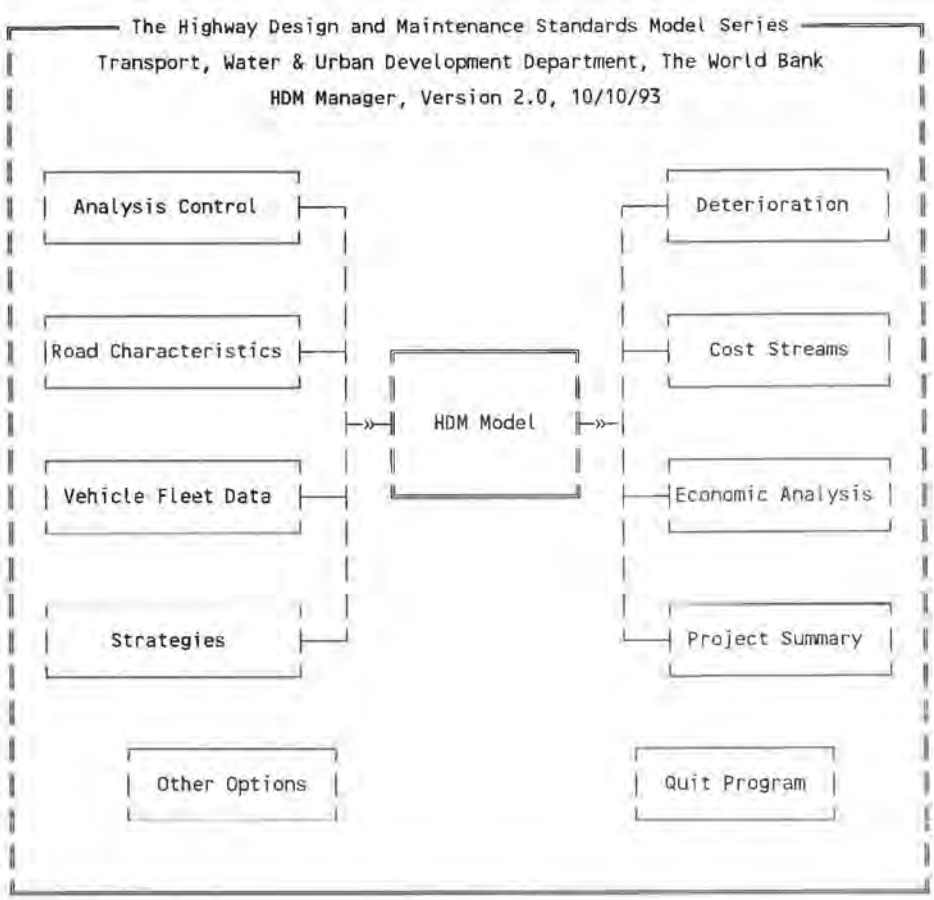

FIGURE 2 HDM Manager main menu.

Road Characteristics

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Description Gravel Road 1 in North Region

Road Type (Paved/Unpaved) U

GEOMETRY

Road Length (km)	100.0	Road Width (m)	6.0
One Shoulder Width (m)	0.4	Effective Number of Lanes	
Rise & Fall (m/km)	40.0	Curvature (deg/km)	100.0
Superelevation (%)	0.0		

ENVIRONMENT

Altitude (m)	500	Rainfall (m/month)	0.0300

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FIGURE 3 Input data screen.

• Step 2—Define the Road Characteristics. Enter the road geometry, road structure, road condition, environment, daily traffic, and the traffic growth.

• Step 3—Define the Vehicle Fleet Data. Enter the vehicle fleet characteristics and the vehicle operation unit costs.

• Step 4—Define the Strategies. Enter the maintenance operations and construction unit costs, define a data bank of possible road agency maintenance and construction policies, and define the road agency strategies being evaluated.

• Step 5—Execute the HDM-III Model. Run the HDM-III model from within the shell environment. Note that after the HDM-III run is completed, the HDM Manager program collects the HDM-III results.

• Step 6—View the Deterioration. Examine the road deterioration behavior of each of the road agency strategies being evaluated.

• Step 7—View the Cost Streams. Examine the financial and economic cost streams (agency costs, vehicle operating costs, and total society costs) of the road agency strategies being evaluated.

• Step 8—View the Economic Analysis. Examine the economic comparison of the strategies being evaluated. The comparison is based on the NPV or IRR of each strategy in relation to a base strategy.

• Step 9—Produce the Project Summary. Select the optimal road agency strategy among the five strategies being evaluated and create a project summary report for the selected strategy.

Users select options on the left-hand side at the main menu to enter the input data to be used in the HDM-III run. When users select any of these options, the corresponding input data screen appears (an example of which is given in Figure 3). At the input screens, users have the following options: edit the information, print the information, store the information into a data set file for future use; retrieve a data set; and save the current information and return to the main menu. HDM Manager does not require all input variables to be entered. The required variables are presented in blue and the optional variables in purple.

HDM Manager evaluates five road agency strategies. Each road agency strategy is composed of one or more than one paved maintenance policy, unpaved maintenance policy, or construction policy. Therefore, before defining the strategies to be evaluated, the users create

Roughness (IRI m/km)

Year	First Strategy	Second Strategy	Third Strategy	Fourth Strategy	Fifth Strategy
1 1993	10.2	10.2	10.2	10.2	10.2
2 1994	10.5	2.7	10.5	10.5	10.5
3 1995	11.2	2.7	2.7	10.7	10.7
4 1996	12.0	2.8	2.7	2.7	10.8
5 1997	12.2	2.9	2.8	2.8	2.7
6 1998	12.3	3.0	2.9	2.8	2.8
7 1999	12.5	3.0	3.0	2.9	2.8
8 2000	11.8	3.1	3.0	3.0	2.9
9 2001	12.8	3.2	3.1	3.0	3.0
10 2002	13.0	3.3	3.2	3.1	3.0
11 2003	13.1	3.4	3.3	3.2	3.1
12 2004	13.3	3.4	3.4	3.3	3.2
13 2005	12.5	3.5	3.4	3.4	3.3
14 2006	13.6	3.6	3.5	3.4	3.4
15 2007	13.8	3.7	3.6	3.5	3.4

Change Years

Next Table   Prev. Table   Select Table   Graph Table   Output Table   Exit

FIGURE 4 Roughness progression screen.

and manage a data bank of road agency policies, for example,

Strategy A, Policy 1: routine maintenance only (from 1993 to 2011).
Strategy B, Policy 1: reseals every 5 years, patching 100 percent of potholes, and routine maintenance (from 1993 to 2002).
Strategy B, Policy 2: overlays every 10 years, patching 100 percent of potholes, and routine maintenance (from 2003 to 2011).

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Strategy X, Policy 1: grading every 90 days and gravel resurfacing (from 1993 to 2011).
Strategy Y, Policy 1: grading every 90 days (from 1993 to 1994).
Strategy Y, Policy 2: paving the road (in 1995).
Strategy Y, Policy 3: overlays when roughness > 4.5 IRI (from 1996 to 2011).

Note that strategies are the road agency alternatives being evaluated. Policies within a strategy are not alternatives, but a sequence, with only one policy being applicable in a given year. Note also that a policy can include a number of maintenance operations that may be scheduled or condition-responsive. HDM Manager evaluates and compares five road agency strategies at a time with the first being the base case (do-minimum or without-project).

After defining all input data, the users run the HDM-III model with the HDM Model option. This option creates all the input data files required by HDM-III and runs the HDM-III program automatically. After the HDM-III run is completed, the users select the Deterioration option to view the road deterioration under the five strategies being evaluated (see Figure 4 for roughness progression). The roughness table presents the roughness progression during the analysis period and is only one of the following 18 available tables:

- Periodic Operations
- Roughness (IRI m/km)
- All Cracks (%)
- Wide Cracks (%)
- Area Raveled (%)
- Pothole Area (%)

- Rut Depth (mm)
- SD Rut Depth (mm)
- Modified Structural Number
- Surface Type
- Gravel Thickness
- Two-Way Average Daily Traffic
- Two-Way Annual Equivalent Standard Axles (000s)
- First Strategy Deterioration
- Second Strategy Deterioration
- Third Strategy Deterioration
- Fourth Strategy Deterioration
- Fifth Strategy Deterioration.

Note that the last five tables present all the deterioration parameters for each of the five strategies (see Figure 5). The users select the Cost Streams option to view the cost streams for the five strategies being evaluated. The following 12 tables are available:

- Financial Agency Capital Costs,
- Financial Agency Recurrent Costs,
- Economic Agency Capital Costs,
- Economic Agency Recurrent Costs,
- Economic Vehicle Operating Costs,
- Economic Total Society Costs,
- Net Economic Benefits,
- First Strategy Costs,
- Second Strategy Costs,
- Third Strategy Costs,
- Fourth Strategy Costs,
- Fifth Strategy Costs.

The users select the Economic Analysis option to view the economic analysis performed by the HDM-III model (Figure 6). Finally, after examining the economic analysis data, the users select the strategy to be carried out, that is, the strategy with highest economic benefits to society. To produce a summary report for the selected strategy (the project), the users select the Project Summary option (Figure 7). The project summary report prints for the without-project case (first strategy) and for the selected strategy the following information:

- Roughness Progression,
- Average Daily Traffic Progression,
- Periodic Maintenance Actions,
- Financial Road Agency Costs,
- Economic Vehicle Operation Costs,

First Strategy - Grading every 90 days + Regrav.

	Year	Operations	Roughness IRI	All Crck %	Wide Crck %	Raveled %	Potholes %	Rut Dpth mm	Mod SN	Surface	Gravel mm	2-Way ADT	Annual 2-Way ESA 000
1	1993		10.2							GRAV	72	200	23.8
2	1994	RESU	10.5							GRAV	193	207	24.5
3	1995		11.2							GRAV	164	215	25.3
4	1996		12.0							GRAV	134	223	26.1
5	1997		12.2							GRAV	103	231	26.9
6	1998		12.3							GRAV	71	240	27.7
7	1999	RESU	12.5							GRAV	189	249	28.6
8	2000		11.8							GRAV	156	259	29.5
9	2001		12.8							GRAV	123	269	30.4
10	2002		13.0							GRAV	89	279	31.4
11	2003		13.1							GRAV	54	289	32.4
12	2004	RESU	13.3							GRAV	168	300	33.4
13	2005		12.5							GRAV	131	312	34.4
14	2006		13.6							GRAV	93	323	35.5
15	2007		13.8							GRAV	55	336	36.6

Change Years

Next Table Prev. Table Select Table Graph Table Output Table Exit

FIGURE 5 Fifth Strategy Deterioration table.

Economic Analysis (million US DOLLARS)

Strategy	Constr. Recons. Costs	Periodic Maint. Costs	Recurrent Maint. Costs	Total Agency Costs	Vehicle Operating Costs	Total Society Costs	Net Present Value	Internal Rate of Return (%)
0.0% Discount Rate								
1	0.00	6.00	0.74	6.74	74.6	81.3	0.0	NONE
2	7.74	1.89	0.84	10.47	45.0	55.5	25.9	17.1
3	7.74	1.89	0.84	10.47	45.8	56.2	25.1	18.7
4	7.74	1.89	0.83	10.46	46.5	57.0	24.3	20.8
5	7.74	1.89	0.83	10.46	47.4	57.9	23.5	MANY
12.0% Discount Rate								
1	0.00	2.40	0.31	2.71	26.7	29.4	0.0	NONE
2	8.50	0.43	0.35	9.28	16.9	26.2	3.2	17.1
3	7.58	0.39	0.34	8.31	17.7	26.0	3.4	18.7
4	6.76	0.35	0.34	7.44	18.4	25.8	3.6	20.8
5	6.02	0.31	0.34	6.67	19.0	25.7	3.7	MANY

NPV Sensitivity   Graph Table   Output Table   Exit

FIGURE 6 Economic Analysis screen.

- Economic Total Society Costs,
- Net Economic Benefits,
- Project NPV, and
- Project IRR.

Analysis Results

Optimum Grading Frequencies for Unpaved Roads

The process used for the determination of the best maintenance strategy consisted in testing various frequencies of grading in order to identify the optimum value at which the highest NPV at a 12 percent discount rate was obtained. More simply and from an economic standpoint, the optimum grading frequency is defined as the breakeven point at which the incremental reduction in vehicle operating costs resulting from an additional grading is equal to the incremental cost of one grading. In the analysis, the base standard implied no grading at all. For all standards, it was assumed that regular routine maintenance would be carried out (that is, ditch and bush clearing, erosion control, drainage structure repairs, and maintenance of vertical signs). Also, but for the base standard, regraveling operations aimed at compensating gravel loss were scheduled to bring the total thickness of gravel back to 10 cm as soon as it reaches 1 cm. The following ranges of intervals between grading operations were tested according to average daily traffic (ADT) volume class:

- ADT<50: from 60 to 730 days, i.e., between 0.5 and 6 gradings/year;
- 50<ADT<100: from 30 to 180 days, i.e., between 2 and 12 gradings/year; and
- 100<ADT<300: from 12 to 180 days, i.e., between 2 and 30 gradings/year.

For all traffic categories, the relationship between the NPV (or roughness) and the level of maintenance was translated by a curve as shown in Figure 8. This curve shows a sharp increase of benefits (or a corresponding high rate of improvement in roughness) as grading operations started and progressed up to a point where the curve began to flatten out, near the optimum value. The most cost-effective frequency of grading was then selected at the critical change of curvature, somewhat be-

HDM Manager: Project Summary

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Project Name : Second Road Construction Project

Run Name : HDM-III Runs for North Region

Run Date : 03/03/93

Road Name: Gravel Road 1 in North Region

Road Length: 100.0 km

Currency: Million US DOLLARS

				WITHOUT PROJECT Grading every 90 days + Regrav.						WITH PROJECT Paving in 1996 + Reseal at 20%			
				FINANCIAL	ECONOMIC	ECONOMIC				FINANCIAL	ECONOMIC	ECONOMIC	NET
YEAR	ADT	OPER	IRI	AGENCY COSTS	V.O.C. COSTS	TOTAL COSTS	ADT	OPER	IRI	AGENCY COSTS	V.O.C. COSTS	TOTAL COSTS	ECONOMIC BENEFITS
1993	200		10.2	0.044	2.309	2.346	200		10.2	0.044	2.309	2.346	0.000
1994	207	RESU	10.5	1.753	2.425	3.662	207		10.5	0.044	2.425	2.462	1.200
1995	215		11.2	0.044	2.594	2.631	215		10.7	0.044	2.532	2.569	0.062
1996	223		12.0	0.044	2.790	2.826	223		10.8	12.044	2.644	11.281	-8.455
1997	231		12.2	0.044	2.913	2.950	231	CONS	2.7	0.050	1.747	1.789	1.161
1998	240		12.3	0.044	3.038	3.075	240		2.8	0.050	1.811	1.853	1.222
1999	249	RESU	12.5	1.753	3.169	4.406	249		2.8	0.050	1.877	1.919	2.487
2000	259		11.8	0.044	3.181	3.218	259		2.9	0.050	1.945	1.988	1.230
2001	269		12.8	0.044	3.445	3.482	269		3.0	0.050	2.016	2.059	1.423
2002	279		13.0	0.044	3.598	3.635	279		3.0	0.050	2.091	2.133	1.502
2003	289		13.1	0.044	3.754	3.791	289		3.1	0.050	2.172	2.215	1.577
2004	300	RESU	13.3	1.753	3.917	5.154	300		3.2	0.050	2.257	2.300	2.855
2005	312		12.5	0.044	3.912	3.949	312		3.3	0.050	2.346	2.388	1.561
2006	323		13.6	0.044	4.261	4.298	323		3.4	0.050	2.438	2.481	1.818
2007	336		13.8	0.044	4.451	4.488	336		3.4	0.050	2.534	2.577	1.911
2008	349	RESU	14.0	1.753	4.645	5.882	349		3.5	0.050	2.634	2.677	3.205
2009	362		13.1	0.044	4.625	4.662	362	RESE	3.6	2.290	2.739	4.671	-0.009
2010	376		14.3	0.044	5.054	5.091	376		3.7	0.050	2.847	2.890	2.201
2011	390	RESU	14.5	1.753	5.279	6.515	390		3.8	0.050	2.961	3.003	3.512
2012	405		13.5	0.044	5.248	5.285	405		3.9	-1.150	3.079	2.262	3.023
Average			12.7						4.7				
Total (undiscounted)				9.425	74.608	81.346				14.016	47.404	57.863	
Total (at 12.00 %)				3.786	26.697	29.406				9.165	19.024	25.691	

Project NPV at 12.00 % Discount Rate: 3.Project Internal Rate of Return (%): 23.9

FIGURE 7 Project Summary table.

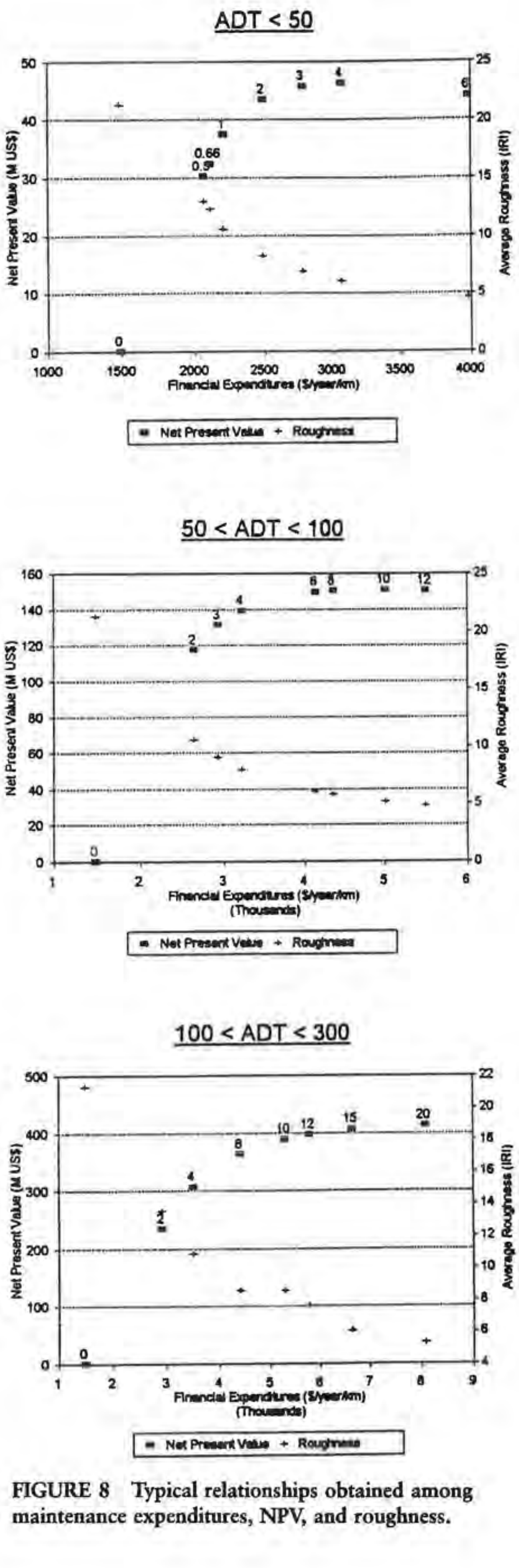

FIGURE 8 Typical relationships obtained among maintenance expenditures, NPV, and roughness.

low the peak of the curve. Table 5 shows the final results, and for comparison, present practices or what the situation has probably been over the last 5 years.

It can be seen that under the near-optimum strategy (or targeted policy)—which also includes suitable regraveling to make up for gravel erosion—the maintenance budget will need to be increased from a current value of about $1,400/km/year to $2,100 km/year, that is, by 50 percent, which is compatible with expected budgetary constraints. Roughness values on the unpaved network would be improved from an estimated present value of 10 IRI to about 7.5 IRI, resulting in substantial savings in vehicle operating costs. Calculations show that increasing the annual allocation for the unpaved network by 50 percent, representing approximately $10 million, would yield annual savings for the users of an amount equal to threefold that value, that is, almost $30 million. The optimum strategy at the peak of the curve would, on the other hand, imply a considerable increase in maintenance budget (doubling the amount of present allocations) and this would be beyond the states' financial capacity.

Optimum Maintenance Policy for Paved Roads

The paved network currently consists of either sand-asphalt carpets or double surface dressings overlying granular lateritic base course and subbase. As can be seen in Table 2, the average traffic volume on this network is of the order of 300 vehicles per day, with only 8 percent of the total network being subjected to traffic density exceeding 500 vehicles/day. The average age of the network is 6 years, although nearly 40 percent of its total 4000-km length is more than 10 years old. Current roughness values are of the order of 4 to 5 IRI, with maximum values generally not exceeding 7 IRI.

Several alternative standards for maintenance were tested:

- Standard 1: Base standard, including essentially routine activities without any repair of the pavement until reconstruction occurs at a critical roughness level of 11 IRI.
- Standard 2: Routine maintenance and patching of all potholes until reconstruction takes place at a critical roughness level of 8.5 IRI.
- Standard 3: Routine maintenance and patching and sealing of pavement with single surface treatment over 30 percent of the total area.
- Standard 4: Routine maintenance, patching of all potholes, and resurfacing with double surface dressing, over 20 percent of the total area.
- Standard 5: Routine maintenance, patching, and overlay with 4 cm of sand-asphalt as soon as the roughness level reaches 6 IRI.

For a low traffic level, that is, less than 300 vehicles per day, the best standard yielding the highest economic rate of return (more than 100 percent) consists of patching of all potholes followed by reconstruction when roughness values reach 11 IRI. Sand-asphalt or asphaltic concrete overlays in thicknesses ranging from 3 to 5 cm with a roughness level of 6 IRI (reached at 7- to 10-year intervals) are best suited to traffic volumes in excess of 300 vehicles per day. Under the patching strategy, roughness is expected to average about 5.6 IRI over an analysis period of 20 years, and the average cost of maintenance to be on the order of $1,800/km/year (as opposed to a current allocation of $700 to $1,000/km/year). Under the overlay strategy, the long-term average roughness on the network would be about 4.6 IRI.

Paving Thresholds

On roads where total transport costs have become excessive as a result of traffic volumes and costly grading or regraveling operations, their improvement by paving is likely to yield significant economic returns, more particularly so in areas with high agricultural potential. Under the project, the highest priorities in this regard have been taken into consideration. Appropriate and generally low-cost design standards have been selected to suit the range of traffic volumes normally encountered, that is, between 100 and 500 vehicles per day. These standards include (*a*) limited earthwork in order to improve grade and horizontal alignments; (*b*) the construction of all drainage facilities, including precast or reinforced concrete bridges; and (*c*) the execution of a pavement consisting of a 30-cm-thick subbase and base course in naturally occurring gravel overlain by a double surface treatment of a thin sand-asphalt carpet 6 to 7 m wide, with shoulder widths varying between 1 and 1.5 m. Typical estimated unit costs range between $100,000 and $120,000 per km, of which paving accounts for about 50 to 60 percent, earthwork for 20 percent, and drainage (including bridges) for 20 to 30 percent of the total.

In order to provide some guidelines for future upgrading and paving programs, HDM Manager was also used to evaluate under various maintenance scenarios (for the unpaved road, that is, the without-project case), the paving thresholds or the minimum average daily traffic above which it would become economically justified to pave the road (IRR of at least 12 percent).

Table 6 summarizes the findings. Assuming that

1. The proportion of commercial vehicles is 50 percent,
2. No generated traffic occurs as a result of paving,
3. No time savings are taken into account in the benefits to users, and
4. The average cost of paving is $115,000 per km,

the threshold traffic volumes generally range between 75 and 125 vehicles per day. The lower threshold value applies to the situation in which a minimum grading frequency is carried out (twice a year) on the unpaved road, and the upper threshold corresponds to a much higher blading frequency (6 times a year). It can also be noted that paving the threshold is sensitive to the growth rate and consequently to the assumed proportion of generated traffic. The higher this rate, the lower the threshold.

Under the conditions normally prevailing in the northeastern Brazilian states, where maintenance activities on unpaved roads have traditionally been kept to a minimum and where both time savings and traffic evolution are enhanced by upgrading and paving op-

TABLE 5 Past or Present Practices and Targeted Maintenance Strategy on Unpaved Network

ADT	KM	Present practices				Targeted strategy			
		Gr/yr	US$/yr	NPV	IRI	Gr/yr	US$/yr	NPV	IRI
<50	10,789	1	1116	66	9.4	2	1625	79	7,2
50-100	3,047	2	1699	208	10,3	4	2605	251	7,6
100-300	2,052	3	2437	470	11.6	6	3657	636	8.2
0-300	15,888	1.5	1398	744	9.9	2.9	2075	966	7.4

Note:

ADT= Average daily traffic

KM= Length of network in km

Gr/yr= Number of gradings per year

US$/yr= Maintenance cost per km per year in US$

NPV= Net present value

IRI= International roughness index in m/km

TABLE 6 Paving Thresholds: Variation of Economic Indicators with Traffic Patterns and Maintenance Policies on Unpaved Network

Traffic		Grading policy for unpaved road (without project case)					
		2 gradings/year		4 gradings/year		6 grading/year	
Growth	ADT	NPV	IRR	NPV	IRR	NPV	IRR
3%/year	25	-6.9	-3.0	-7.5	-5.9	-7.6	-6.6
	50	-3.8	5.4	-5.6	1.1	-6.3	-1.0
	75	0.2	**12.3**	-3.0	7.0	-4.4	4.0
	100	5.1	19.3	0.7	**13.0**	-1.7	9.3
	125	10.2	26.0	4.7	18.6	1.5	**14.2**
	150	15.3	32.5	8.7	23.9	4.8	18.8
	175	21.2	39.8	13.7	30.2	9.1	24.3
	200	27.0	47.1	18.6	36.2	13.2	29.5
4.5%/yr	25	-6.6	-1.2	-7.3	-4.4	-7.5	-5.5
	50	-2.8	7.4	-5.0	3.1	-5.9	0.9
	75	1.8	**14.6**	-1.8	9.4	-3.5	6.3
	100	7.5	21.7	2.6	**15.5**	-0.1	11.8
	125	13.3	28.4	7.2	21.1	3.6	**16.8**
	150	19.3	35.0	12.0	26.6	7.6	21.4
	175	25.9	42.4	17.8	32.9	12.6	27.0
	200	32.4	49.8	23.4	39.0	17.5	32.3
6%/year	25	-6.1	0.9	-7.1	-2.3	-7.3	-3.7
	50	-1.7	9.6	-4.2	5.3	-5.3	2.9
	75	3.7	**16.7**	-0.3	11.6	-2.3	8.6
	100	10.3	24.0	4.9	**17.9**	1.8	**14.2**
	125	17.2	30.9	10.4	23.7	6.4	19.4
	150	23.9	37.6	16.0	29.1	11.1	24.1
	175	31.4	45.0	22.7	35.6	16.9	29.8
	200	38.9	52.5	29.3	41.7	22.7	35.1

erations, the conclusion of the analyses is that consideration should be given to the possibility of paving a road whenever current traffic volume exceeds some 50 vehicles per day. This is particularly so if gravel materials are scarce and the proportion of commercial vehicles is greater than 50 percent.

Monitoring the Maintenance Program

Because of the improvements needed in these three states, both institutionally and financially, before the optimum strategies can effectively be put into practice, implementation of the new policies was scheduled to take place progressively, in parallel with institution building and budget increases. It was assumed that full momentum would be reached by the fourth and fifth year of the project. Consequently, the monitoring program was designed to check, on the basis of a series of performance indicators, the achievement of targets rising gradually from their present level to the desirable level consistent with the selected maintenance strategy.

Table 7 presents a typical subproject implementation schedule with monitoring indicators and targets.

TABLE 7 Typical Subproject Implementation Indicators and Targets

Program/Objective	Indicators	1994	1995	1996	1997	1998
Physical Implementation						
Rehabilitation & Resurfacing	Contracted (km)	60	60	60	60	60
	Executed (km)	60	60	60	60	60
Routine Maintenance	Patching (m3)	1,100	1,000	900	800	700
	Grading (thousand Km)	18.0	18.0	18.0	18.0	18.0
	Regraveling (thousand m3)	700	700	700	700	700
Upgrading & Paving	Contracted (km)	400	200	200	200	
	Executed (km)	200	200	200	200	200
Funding and Cost-Recovery						
Maintenance	Maint. Budget (US$m)	14.0	15.0	16.0	17.0	17.0
Rehabilitation & Resurfacing	R. & R. Budget (US$m)	1.2	1.2	2.0	1.4	.2
Cost-Recovery	% Maintenance Expenditure	100%	100%	100%	100%	100%
	% Total Expenditure	30%	30%	30%	30%	30%
Institutional Development 1/						
Maintenance	% Length Contracted (km)	30%	40%	50%	60%	70%
Staffing	Nb. DEOVI Staff	1,200	1,150	1,100	1,050	1,000
Training	Nb. Trainee-Week	200	250	250	200	100
Network Condition						
Paved	80% Length with IRI <	6.0	5.5	5.0	4.5	4.0
Unpaved, ADT<50	80% Length with IRI <	13.0	12.0	11.0	10.0	9.0
Unpaved, 50<ADT<100	80% Length with IRI <	15.0	14.0	12.0	10.0	9.0
Unpaved, ADT>100	80% Length with IRI <	18.0	16.0	14.0	12.0	10.0

1/ In addition, road condition, traffic and accident surveys are to be carried out each year on the entire state network in accordance to guidelines set forth in the Operational Manual.

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