Issues Related to Administration of Low-Volume Roads in Developing Countries

JACOB GREENSTEIN

The predominant need in the administration of rural roads is to improve the maintenance and performance of the existing network rather than to construct new roads. To achieve this goal, an economic analysis of costs and benefits related to the level of accessibility and the economic life of the road network is normally required. In rural areas where the road is a component of an area development program and traffic volumes are low (less than 50 vehicles per day), a socioeconomic methodology that examines the relationship between road accessibility, agricultural and forestry production, and social services has been applied to evaluate costs and benefits of investments of the whole program, including its road improvement component. Rural investment is most efficient when the most economic type of roadway and the complementary agricultural/forestry social investments are jointly optimized. The principal benefits achieved are reduced transport costs, increased area of agricultural land in production, increased yield per unit area, and all-weather accessibility. One of the most important tasks to be done by local governments is the condition inventory and evaluation of the road network. Other issues discussed include design of low-cost bridges and water crossings, optimization of routine and periodic maintenance expenditures, and the application of environmental procedures in the administration of low-volume roads.

Rural roads are often significant in terms of mileage in the overall network, tonnage transported, and socioeconomic value. Two-thirds to three-quarters of the world's roads are low-volume roads (LVRs). LVRs are usually constructed and administered in an environment of minimum investment and are usually the first and primary link between raw materials and the world market. One of the Inter-American Development Bank (IDB) objectives is to assist rural roads authorities to develop the most practical and economical road improvement investment programs and to administer efficiently these rural road networks (*1,2*), including their environmental impacts.

The socioeconomic evaluation criteria used to assess road improvement distinguish between existing roads with considerable traffic and roads with a low volume of traffic. Both procedures are presented in the paper in the context of the following issues related to road planning and administration: alternatives for rural road improvement, inventory and road evaluation aided by means of knowledge base expert systems, simplified socioeconomic procedures for road improvement, environmental issues related to rural roads improvement and maintenance, planning and administration of forestry roads, design of low-cost bridges and water crossings, and optimization of routine and periodic pavement maintenance expenditures of gravel roads.

Inter-American Development Bank, 1300 New York Ave., N.W., Washington, D.C. 20577.

ALTERNATIVES FOR ROAD IMPROVEMENT

The main objective of rural road planning is to develop an investment program that can efficiently allocate and use available resources by developing priorities for road improvement and maintenance activities (*1–4*). To achieve this, a socioeconomic analysis of costs and benefits related to the level of accessibility and the economic life of the road network is carried out (*5*). The analysis requires the estimation of economic costs and benefits resulting from the improvements of rural road networks. These normally consist of eight different types of pavements:

1. Asphaltic concrete or sand asphalt,
2. Surface treatment (single, double, and sometimes triple),
3. Chemically stabilized base course (lime, cement) with or without blacktop,
4. Crushed stone or gravel base course with or without blacktop,
5. Gravel or subbase without blacktop,
6. Stone roads,
7. Compacted selected (lateritic) local materials, and
8. Earth roads.

The first seven types of roads are designed to provide all-weather accessibility.

Asphalt roads usually have representative design speeds of 50 to 90 km/hr, whereas gravel roads are usually in the range 25 to 50 km/hr. These upper and lower limits represent design speeds for level and mountainous terrains, respectively, and may also vary depending on the local topographical and environmental conditions. The total width of an asphalt road is usually between 7.2 and 9.7 m. The design speed of a Type 8 earth road is usually between 20 and 30 km/hr, and its width varies between 3 and 4 m.

For each uniform road link there are several alternative improvements. For example, there are more than seven alternatives to upgrade Road Type 8 because there are seven types of higher class road, 1 to 7, and each of these may be varied to provide additional alternatives. To determine the most economic upgrade of the rural road network, it is necessary to analyze a wide range of road improvement alternatives and to select the combination of network betterment that results in the highest marginal rate of return. In other words, for each improvement alternative of the road network, it is necessary to determine, for the life of the projects, the streams of costs and benefits and to calculate the economic priority indicators such as internal rate of return (IRR), first year rate of return (FYRR), net present value (NPV), and benefit cost (B/C) ratio. The economic indicators are calculated for each road link and for the improvement of the entire network.

INVENTORY AND ROAD EVALUATION

Good road management requires continual updating of information about the road network. This is achieved by means of a road inventory that identifies each road link and evaluates both the engineering characteristics and the condition of the road elements, including alignment, drainage, pavement materials, and surface condition. During the inventory, notes are kept indicating the need for such road improvements as pavement strengthening, replacement of drainage facilities, shoulder improvements, and other emergency work not covered by routine or periodic maintenance. The inventory team normally analyzes and evaluates about 40 road parameters (see Table 1). Each parameter has on the average three to five quantitative or qualitative values that should be evaluated in the field. For example, the surface and drainage conditions are evaluated qualitatively on a scale of 1 to 5, with 1 being the worst and 5 the best (*5*). Also, if some of the road elements are in poor or bad condition and accessibility is limited, the inventory team is asked to determine what kind of road improvement is required (e.g., pavement overlay, pavement strengthening with base course with or without asphalt, raising of the surface elevation, or replacement or addition of culverts).

The inventory team has to make accurate assessments of at least 150 road engineering indicators, and an inaccurate evaluation of any of these could distort the planning of improvement, maintenance, and rehabilitation. The author's experience of more than 15 years in planning and designing rural roads in developing countries indicates that despite the efforts made in the training of evaluation teams, a strong need exists to screen, verify, and adjust the information gathered in the field during the inventory. To assist the process, and to obtain greater uniformity and reliability in the results, it is helpful to use a logic analysis expert system computer program.

Once the road links are identified and evaluated, the road network's requirements for improvement and maintenance are determined (*5*). Some partial instructions and an example of a road inventory carried out in Ecuador are presented in Table 1. Special expertise is needed to conduct field evaluations of the engineering characteristics of the subgrade and pavement systems given in Table 1 (Section 4, Boxes 401–423). In this section, the inventory team has to determine among other things the subgrade and pavement California bearing ratio (CBR), the type and severity of surface distress, and the quality or efficiency of the routine maintenance work. The three most common types of surface distress and their severity are identified in Boxes 407–413. The following are types of surface distress for roads with a blacktop (the eight types of surface distress most commonly found in rural roads without blacktop are italic):

1. *Potholes*,
2. Weathering/raveling,
3. Alligator cracking,
4. Slippage cracking,
5. Block cracking,
6. *Edge failure*,
7. Longitudinal/transverse cracking,
8. *Lane/shoulder drop*,
9. *Bumps and sags*,
10. *Depression*,
11. *Corrugation*,
12. Shoving,
13. *Swelling*,
14. *Rutting*,
15. Bleeding, and
16. Polished aggregate.

While in the field, the engineering evaluation team is also required to identify the most practical and economical alternative for road improvement (Table 1, Boxes 501–515). Targeted improvements include the rehabilitation of new bridges and culverts (Boxes 501–507), determination of the minimum embankment rise in elevation to prevent flooding or overtopping during the rainy season (Box 508), or improvement of the geometry or drainage characteristics of the roads by means of excavation (Box 509). Another conclusion is related to urgent needs for pavement repair or maintenance (Boxes 510–515). The inventory team must determine the three most urgent needs for pavement repair. The 11 most common types of pavement repairs on rural roads are pothole filling; pavement strengthening with an additional 7 to 30 cm of granular material with or without blacktop; shoulder improvement; grading, shaping, and compacting granular pavement without blacktop; crack sealing; skin or partial depth patching; full-depth patching; application of heat and sand; surface treatment; asphalt overlay; and pavement reconstruction.

Expert systems are interactive computer programs that use expert knowledge to obtain enhanced levels of performance in a narrow problem area (*6*). They contain a collection of specific domain knowledge called a knowledge base (KB) and a general problem-solving ability called an inference engine. Expert system building tools are now available for microcomputers that allow experts in other fields to prepare expert systems in their areas of specialization. These building tools, known as shells, are rapidly emerging as a new class of computer program, joining the ranks of word processors, data base managers, and spreadsheets.

The need for a rural road inventory expert system arose because engineers who have been taught the basic mechanics of the procedures have occasionally performed poorly, failing to notice gross inconsistencies in both the data and the conclusions. The rural road inventory expert system package seeks to upgrade the performance of engineers with limited experience. It was prepared using commercially available shells and contains KBs for analyzing the rural inventory data as well as its conclusions and recommendations (*5*).

SIMPLIFIED SOCIOECONOMIC PROCEDURE FOR ROAD IMPROVEMENT

Saving of transportation costs is not always sufficient to justify rural road improvement in countries such as Ecuador, Peru,

TABLE 1 Sample of Rural Road Inventory Data Sheets (7)

ENGINEERING CHARACTERISTICS LENGTH OF THE SUBSECTION (Decim/km)	(LNG)	[127]	201-204
NO. OF MONTHS WITH NO ACCESSIBILITY	(MNA)	[0]	205
NO. OF EXISTING BRIDGES	(NEB)	[1]	206
NO. OF EXISTING CULVERTS	(NEC)	[29]	207-208
TYPE OF TERRAIN (1-level, 2-hilly, 3-mountainous)	(TER)	[2]	209
TYPE OF ROAD SURFACE (1-asphalt concrete, 2-asphalt surface treatment, 3-chemically stabilized, 4-crushed stone base, 5-gravel road, 6-stone road [empedrado], 7-compacted selected local materials, 8-earth road)			
EFFECTIVE, OR USED ROAD WIDTH (MET)	(ERW)	[5.0]	211-214
TOTAL ROAD WIDTH INCLUDING SHOULDERS (MET)	(TRW)	[6.0]	215-218
SHOULDER WIDTH (MET)	(SWH)	[0.5]	219-221
TYPE OF SHOULDER (0-does not exist, 1-paved, 2-granular or stabilized, 3-soil, 4-others)			
ROAD CLASSIFICATION (1-main, 2-principal rural, 3-secondary rural, 4-penetration)	(RCL)	[3]	223
FIELD EVALUATION OF THE ROAD ELEMENTS			
ACTUAL TRAVELING SPEED (km/h)	(ATS)	[15]	301-302
AVERAGE DAILY TRAFFIC	(ADT)	[80]	303-306
CONDITION OF THE HORIZONTAL ALIGNMENT (1-very bad, 2-bad, 3-poor 4-fair, 5-good)	(CHA)	[4]	307
POSSIBILITY OF IMPROVING HORIZ. ALIGNM. (1-3)	(PIA)	[3]	308
LONGITUDINAL GRADE (1-over 10% to 5-less than 2%)	(LGR)	[4]	309
SURFACE CONDITIONS (1-very bad to 5-good)	(RSC)	[2]	310
CONDITION OF SHOULDERS (1-very bad to 5-good)	(CSH)	[2]	311
VISIBILITY OF TAKEOVER (1-very bad to 5-good)	(VTO)	[4]	312
DRAINAGE CONDITIONS (1-very bad to 5-very good)	(RDC)	[3]	313
SUBGRADE CONDITIONS (1-very bad to 5-good)	(SUB)	[3]	314
ALTITUDE ABOVE SEA LEVEL	(ALT)	[2100]	315-318
CLIMATE CONDITIONS (1-tropical, 2-sub-tropical, 3-arid)	(CLC)	[2]	319
EVALUATION OF THE SUBGRADE AND PAVEMENT SYSTEM SOIL CLASSIFICATION (26 possibilities)	(SCL)	[CL]	401-402
ESTIMATED SUBGRADE CBR	(CBR)	[4]	403-404
ESTIMATED PAVEMENT CBR (unsurfaced roads)	(CPR)	[12]	405-406
DETERMINATION OF THE THREE MOST COMMON SURFACE DISTRESSES	(RD1)	[01]	407-408
(1-16 and 1-8 for roads with and without blacktop)	(RD2)	[11]	409-410
	(RD3)	[14]	412
THE SEVERITY OF EACH DISTRESS (1-high, 2-medium, 3-low)	(DS1)	[1]	413
	(DS2)	[1]	414
	(DS3)	[1]	415
EFFICIENCY/QUALITY OF PAVEMENT MAINTENANCE (1-poor, 2-limited, 3-adequate)	(RML)	[1]	416
ESTIMATED DATE OF LAST PAVEMENT OVERLAY OR CONSTRUCTION (month/year)	(LPO)	[0684]	417-420
HAULAGE DISTANCE OF MATERIALS (km)	(DCM)	[110]	421-423
IDENTIFICATION OF ROAD IMPROVEMENT AND MAINTENANCE NEEDS			
NUMBER OF NEW BRIDGES NEEDED	(NBR)	[00]	501-502
TOTAL LENGTH OF NEW BRIDGES (meters)	(TBL)	[000]	503-505
ESTIMATED NUMBER OF NEW CULVERTS	(NCL)	[02]	500-507
STRENGTHENING, RAISING OF EMBANKMENT HEIGHT (1-over 1.0 meters to 5-0.0 meters)	(REH)	[5]	508
AVERAGE EXCAVATION OR CUT DEPTH NEEDED TO IMPROVE THE ROAD CHARACTERISTICS (1-over 8.0 meters to 5-less than 0.6 meters)	(CTH)	[3]	509
URGENT NEED OF PAVEMENT REPAIR OR SPECIAL MAINTENANCE NEEDS (1 to 10)	(PRB)	]01]	510-511
	(PBR)	[04]	512-513
02* 17+	(PRC)	[03]	514-515

* Suggested by the computer: 02 denotes the number of activity of pavement repair
\+ Suggested by the computer: 17 denotes the thickness of the new base in cm.

and Bolivia (3,4). The rural economic growth of these countries has often been substantially hindered by poor road accessibility, which has resulted in increased vehicle operating costs and traffic hazards. A socioeconomic methodology has been developed on the basis of the relationship between road accessibility, agricultural production, and economic and social indicators for rural improvement. This can be used to evaluate the benefit of investments from road improvement in rural areas (3,4). The principal conclusion is that rural investment can only be optimized when the most economic type of road network and the complementary agricultural investments are determined simultaneously. The main benefits are

- Reduced transport costs through the substitution of small and uneconomical vehicles, animal transport, or river boats by larger and more economical motor vehicles;
- More effective use of agricultural land by conversion from subsistence farming to commercial production;

- Increased yields through the introduction of more modern farming equipment, fertilizers, pesticides, and technical assistance;
- Substitution of high-value perishable crops grown for the domestic market for long-life staple crops; and
- All-weather accessibility, which permits lower storage requirements and related inventory costs as well as the harvesting of crops when they are ready for marketing, regardless of weather conditions.

When these additional factors generate more benefits than the total expenditures required during the lifetime of the road and produce an IRR and FYRR greater than 12 percent, the road investment is normally considered justified (*1,3,4*).

DETERMINATION OF THE MOST ECONOMICAL TYPE OF ROAD

Determination of the optimum type of road for each level of traffic is done by analyzing the relationship between the total transportation cost and the traffic volume. The total transportation cost for a given road network includes reconstruction, rehabilitation, maintenance, and vehicle operating cost (VOC) expenditures during the economic lifetime of the project. During this period, most of the benefits of the complementary agricultural investment can be developed, justifying the road network's improvement (*1,3,4*). For any given traffic projection, the total transportation cost varies with type of road, surface conditions, rehabilitation and maintenance costs, the engineering properties of the existing soils and materials, and the local environmental characteristics. The conclusions of this road screening or threshold analysis (*2,3,7*) are summarized in the following table:

Road Type (Minimum Transportation Cost)	*Traffic Volume (Vehicles per Day)*
8 (earth)	less than 50
5 or 6 (gravel or stone)	50–100
3 or 4 (crushed or stabilized gravel, stone)	101–250
2 (asphalt surface treatment)	over 250

According to these tabulations, when the traffic volume is between 50 and 250 vehicles per day, it is better to construct an all-weather gravel road than an asphalt treatment road. When the ADT is less than 50 vehicles per day, savings in VOC and road maintenance costs are not usually sufficient to justify the improvement of a dry season dirt road to an all-weather gravel road. Improving traveling safety and reducing road accidents should also be considered in road investment programs, since traveling safety is related mainly to roads with divided lanes and controlled accesses (*1*). It has not yet been proven that improvement of low-volume roads results in significant economic savings due to accident reduction, and therefore this is not considered in this paper.

COMPLEMENTARY RURAL INVESTMENT COSTS

Segments of the road network that play a principal role in connecting production centers with markets and that carry sufficient projected traffic volume to justify an upgrade are analyzed in terms of the net increase in the economic value of the production of goods and services that result from the road investment. In this case, an improvement of the road accessibility, such as an upgrading from a dry-season dirt road to an all-weather road, may contribute to increasing the value of production in the zone affected by road improvement through lower costs of inputs, lower costs of marketing, and higher farm gate yield and prices.

In rich agricultural areas, road improvement can often be economically justified without the need for complementary rural investments (*3,4*). In this case, the road improvement increases the value of production, lowers storage requirements and related inventory costs, and allows harvesting the crops when they are ready for marketing, regardless of weather conditions. On the other hand, in many rural areas of countries such as Ecuador, Peru, and Bolivia, complementary agricultural investment is essential to justify such road projects. In other words, in many rural development projects, road rehabilitation and agricultural development (a complementary investment) are necessary to economically justify rural road investments.

AGRICULTURAL AND TRANSPORTATION BENEFITS OR VALUE ADDED ACHIEVED THROUGH ROAD IMPROVEMENT

Value Added Resulting from Improvement in the Agricultural Farming System

Three major farming systems were identified: traditional, semitechnical, and technical. The traditional system is characterized mainly by the use of the family work force. Seeds are from the last harvest, and neither fertilizers nor technical assistance is used. Yields are low, and a large portion of the harvest is for local subsistence. Approximately 72 percent of the cultivated areas in the seven provinces studied in Ecuador in 1985 were identified as traditional (*3,4*). The semitechnical system is characterized by the use of machinery for land preparation, fertilizers in a selective form, and improved seed. The farmer uses limited technical assistance and credit. Yields are varied, and the harvest is frequently mechanized. Approximately 27 percent of the area studied in 1985 was identified as semitechnical or partially mechanized. The technical system is totally mechanized, capital-intensive, and characterized by total control of seed quality and the use of fertilizers and chemical elements. The farmer makes extensive use of technical assistance and credit; yields are very high, and the harvest is frequently mechanized. An estimated 1 percent of the studied area was identified as technical in 1985.

The main constraints to the improvement of the agricultural system from traditional to semitechnical are the lack of adequate infrastructure (principally all-weather roads for market access), the use of inputs (such as improved seed and fertilizers, which should be brought in from outside the zone), and the introduction of technical assistance. To estimate the value added by changing the farming system, a production function was developed for about 60 main agricultural products in the area studied (e.g., coffee, cacao, bananas, citrus fruit, potatoes, garlic, onions, and tomatoes). For each agricultural item, the production function related the production cost and yields to the farming system. A high rate of return can be achieved by improving the agricultural method in conjunction with improvements to the road network. This economic return on the road component is approximately 30 to 35 percent, or

U.S. $18,000/km/year, compared with the average investment in gravel road improvement. This high annual benefit can usually be achieved during an approximately 7- to 10-year transition period in which the traditional agricultural production system is improved into the semitechnical method.

Value Added Resulting from Reducing Transportation Costs

Savings on transportation costs in rural South America are usually obtained in the following ways: (*a*) by reducing the VOCs by using roads with better surface conditions or more economical vehicles (*3,4,8*) and (*b*) by reducing the cost of transporting agricultural products by using motorized vehicles on new roads instead of animals in areas where roads do not now exist (*3,4*).

The transportation of agricultural products from rural areas to market in South America is often done by pickup or light trucks that carry up to 1800 kg. The transportation cost in Ecuador, in normal road conditions, in 1985 was U.S. $0.17/ton/km (*4*). This vehicle transportation unit cost was only one-fifth to one-sixth of the cost of animal transport by mules. Therefore, the annual VOC saving of an average ADT of 40 vehicles is approximately U.S. $3,500/year/km, or approximately 6 to 7 percent of the investment needed to construct a gravel road. In rural tropical areas in Ecuador, the Selva of Peru, and the eastern zone in the departments of Beni and Santa Cruz in Bolivia, the use of combined land and river transportation is common. An investment of about 10 percent of the construction costs of a new road can permit farmers to use river transportation instead of new roads, resulting in a significant reduction in costs. This small investment is needed for constructing docks, parking lots, facilities for loading and unloading, and the like. On the other hand, passenger transportation costs for river transportation are significantly higher (*4*). These references indicate that if the ADT is equal to, or less than, 55 vehicles per day and if it mainly includes passenger pickups, it is not usually feasible to construct a new road. It will be more economical to use the river as a link in the rural transportation network until the traffic volume increases.

When the entire rural transportation network of roads and river navigation is evaluated, the flows of people and cargo are assigned to each link so that all the productive area is covered adequately and economically. Each road or river link serves the optimum area of influence, and the entire network covers all the productive areas. Generally, when there are no topographical or environmental obstacles, the area of influence of each road segment extends approximately 2 to 3 km. The extension of the area of influence is determined to permit local farmers to bring their products from the farthest point of their farms to the road during the day the products are harvested, preferably in less than 4 hr. Special local conditions such as difficult mountainous terrain, rivers, wetlands, natural resources, or protected flora/fauna may affect the actual area of influence on road links and therefore the planning and administration procedures of the rural transportation network.

Value Added from an Increase in the Area Under Cultivation

This value added is generally small and varies between 0 and 15 percent (*4*). As an example, the area influenced by the road distance extends 2.5 km in both directions (i.e., 500 ha/km of the road link). Assume that the average marginal increase in the cultivated area is (7.0 percent) (500 ha) = 35 ha/km. The value added for cacao (*4*) is U.S. $630 and U.S. $1,750/km/year for traditional and semitechnical farming methods, respectively.

Other Value Added

Benefits result from eliminating losses in existing crops caused by lack of access, poor surface conditions, and lowering of storage requirements and related inventory costs. This value added includes the benefits of eliminating the lack of accessibility to markets, having better agricultural products, and harvesting the crops when they are ready for marketing, regardless of weather conditions. More explanation of the way road accessibility is improved and leads to increased value added is given elsewhere (*3*).

ECONOMIC ANALYSIS

The purpose of the economic evaluation is to ensure that projects are only selected when the preceding factors generate more benefits than the total expenditure required during the lifetime of the project. When the internal rate of return exceeds the opportunity cost of capital, the road investment is normally considered economically justified. Each cost and benefit item is determined uniquely to ensure that there is no double counting. As an example, the reduction of the VOC is credited only to the transportation value added and not to the improvement of the agricultural farming system or to the reduction of production costs. The stream of economic costs and benefits is calculated for each transportation link and for the entire network, determining the related economic indicators such as IRR, FYRR, and NPV. The FYRR of each uniform link segment is used to determine the optimum year of rehabilitation and to ensure that the improvement of high-return roads is not delayed to accommodate barely feasible roads. The final order of priority for road improvement should also include social consideration and an evaluation of the capability of the local government and the local construction industry to carry out the projects as needed.

SOCIAL CONSIDERATIONS

South American governments and international finance agencies, such as the World Bank and IDB, specify that the results of the economic evaluation must be analyzed together with social factors (*1,2,9*). Population and the rate of illiteracy in the influence area of the local network are among the other social indicators used to determine investments of road improvements. The higher the population density and the higher the rate of illiteracy, the greater the need for transportation to local markets, public institutions, health and educational facilities, and commercial centers. For any given investment, the social benefits achieved from rural road improvement will be greater for a higher population density and for higher illiteracy rates (*3,4,10*). The distribution of net economic benefits accruing to low-income groups is another important social indicator. The definition of low-income groups and the procedures to measure this social indicator are presented in guidelines for the preparation of loan applications of IDB (*1*).

IDB recommends the investigation of several other concerns related to the impact of transportation on the human environment, such as safety aspects and impact on land prices, historical or archeological sites, and indigenous groups (*1,2,11,12*). These guidelines emphasize the following social issues:

- Upgrading of unpaved rural roads to paved standards should consider the demand and volume of slower-moving traffic that may be either displaced or put at risk as trucks and cars travel at higher speeds. If necessary and feasible, slow-speed lanes or pathways should be provided.
- The increase in land values along improved roads may be accompanied by land speculation at the expense of local interests and cultural values.
- Penetration roads that bring Amerindian groups into contact with larger society can have serious sociocultural impacts, especially where traditional tenure and resource use patterns are disrupted, jeopardizing indigenous livelihoods and welfare.
- Effective management of development and resource use in areas to be served by transportation infrastructure is essential for successful implementation of plans that address environmental and related social issues.

ENVIRONMENTAL ISSUES RELATED TO IMPROVEMENT AND MAINTENANCE OF RURAL ROADS

Environmental issues play an important role in the planning and administration of low-volume roads (*2*). On each project, it is necessary to identify the potential environmental impacts at the beginning of the project cycle and to classify the proposed activity in one of four categories according to the potential impacts, as follows: (*a*) beneficial to the environment, (*b*) neutral to the environment, (*c*) moderate potentially negative environmental impacts (but sound solutions exist for protection or remediation), or (*d*) significant potentially negative impacts. Road maintenance projects that improve surface and drainage conditions or that result in improvement of dust control may be classified as beneficial or neutral. Road improvements that require wetland replacement or erosion control may be classified in the third or fourth categories. The conclusions of the environmental analysis are implemented in the special provision of the construction documents to minimize or eliminate any damage or risk to people or the environment. A sample of potential negative impacts and the measures to mitigate them is presented in Table 2. As an example, to minimize erosion from fresh road cuts and fills, it is recommended to limit earth moving to the dry periods; protect susceptible soil surfaces with special mulch; protect drainage channels with berm, straw, or fabric barriers and install sedimentation basins; and seed or plant the susceptible erodible surfaces as soon as possible.

LOW-COST BRIDGES AND WATER CROSSINGS

It is well known that the transport of goods in some South American countries is mainly performed by the trucking industry, which saves money by overloading its trucks. Recent projects in Ecuador, Colombia, and Venezuela financed by IDB and the World Bank indicate that little is currently being done on the main roads to control truck overloading. As a result of this evidence, the structural divisions of some road authorities are using a 25 percent increase of live load, as compared with the AASHTO HS-20 standard of 33 tons. A lower standard live load of the 24.5-ton HS-15 truck was used only occasionally in Ecuador in the design of rural bridges. Recent economic and transport studies in Ecuador indicate that the actual vehicle loading on many rural roads is significantly lower (*13*). The largest vehicle on more than 90 percent of the roads is a two-axle truck with a total weight of less than 10 metric tons. About 75 percent of the vehicles are pickup trucks and light buses and trucks with a total weight of 2 to 6 tons. In addition, the projected demand and economic growth and the low standard of the road and pavement make the use of oversized or overloaded vehicles infeasible (*3,4,10,13*). Only in a few rural locations—regions with heavy traffic from timber-producing areas or banana plantations—can an AASHTO standard HS-15 live load be economically justified. These relatively few roads usually have higher design standards: a 6.0- to 7.2-m-wide base course pavement with or without blacktop is usually used. On the basis of these economic and traffic forecast analyses, it appears that it was practical and economical to adopt lower design standards for live loads on many of the low-cost rural bridges. The following three load categories were adopted (*13*): an M6 truck with 1200 and 4800 kg on the front and rear axles, respectively; an M10 truck with 2000 and 8000 kg on the front and rear axles, respectively; and an HS-15 load with 2720 kg on the front axle and 10 880 kg on each of the two rear axles, for a total of 24 480 kg. The AASHTO standard HS-20 live load was not found to be economically justified for these low-cost roads. Nevertheless, it is still used by the Colombian road authority for the design of rural bridges.

Hydrology design criteria may also play an important role in reducing construction expenditure on low-cost bridges. The recommended storm period in the design of bridges on rural roads is 25 years (*13*). The recommended clearance between the maximum storm water level and the bridge should be 1 ft unless the water velocity is very low. If the stream's ground slope is less than 0.5 percent, the maximum velocity is less than 10 ft/sec, and no accumulation of debris is expected, the water clearance could be reduced from 1.0 to 0.5 ft. Experience with design of low-cost bridges (*13*) shows that the average total cost of a one-lane low-cost bridge is approximately 20 to 40 percent of that of a standard two-lane bridge. Additional cost savings can be obtained by constructing a ford. Graveled fords are commonly used in the mountainous and hilly regions (*13*). Fords are used as low-cost water crossings on almost every unpaved rural road in this region. The construction of this type of crossing is usually labor-intensive. The surface of graveled fords usually performs adequately for 3 to 5 years in the Ecuadorean Andes. Maintenance is simple and is performed by manual labor with a relatively minor cost. Experience in Ecuador clearly indicates that the construction and maintenance costs of fords are always a small fraction of those for single-lane, low-cost bridges. They cost U.S. $50 to U.S. $100 per linear meter, or less than 5 percent of a two-lane standard bridge when local materials are available.

TABLE 2 **Rural Roads Environmental Impacts (2)**

	POTENTIAL NEGATIVE IMPACTS	MITIGATING MEASURES
	Direct: During Construction	
1.	Erosion from fresh road cuts and fills and temporary sedimentation of natural drainage ways.	Limitation of earth moving to dry periods. Protection of most susceptible soil surfaces with mulch.
2.	Air pollution from: construction site dust, rock crushing plants, asphalt plants.	Appropriate controls, such as considering wind intensity and direction in construction schedule.
3.	Ground and water contamination by oil, grease, and fuel in equipment yards.	Collection and recycling of lubricants. Precautions to avoid accidental spills.
4.	Creation of stagnant water bodies in borrow pits, quarries, etc. suited to mosquito breeding and other disease vectors.	Assessment of vector ecology in work areas and employment of measures to avoid creating habitats.
5.	Environmental and social disruption by construction camps.	Careful siting, construction and management of construction camps.
	Direct: Permanent	
6.	Destruction of buildings, vegetation and soil in the right of-way, borrow pit sites, waste dumps, and equipment yards.	Alternative alignments. Harvest and utilization of public domain forest resources prior to construction.
7.	Interruption of subsoil and overland drainage patterns (in areas of cuts and fills).	Installation of adequate drainage works.
8.	Landslides, slumps, slips and other mass movements in road cuts.	Route alignment to avoid inherently unstable areas. Design of drainage works to minimize changes in surface flows and adequate to local conditions, according to prior surveys. Stabilization of road cuts with structures (concrete walls, dry wall masonry, gabions, etc.).
9.	Increased suspended sediment in streams affected by road cut erosion, decline in water quality and increased sedimentation downstream.	Establishment of vegetative cover on erodible surfaces as soon as possible. Establishment of retention ponds to reduce sediment load before water enters stream.
10.	Marred landscape (scars from road cuts, induced landslides and slumps, etc.)	Tourist site access roads planned with regard for visual aesthetics. Grade limitations to avoid cutting and filling where scenery would be spoiled. Maintenance and/or restoration of roadside vegetation.
11.	Contamination of ground and surface waters by herbicides for vegetation control and chemicals (e.g., calcium chloride) for dust control.	Reduction of use. Alternative (non-chemical) methods of control.
12.	Accident risks associated with vehicular traffic and transport, that may result in spills of toxic materials.	Regulation of transport of toxic materials to minimize danger. Prohibition of toxic waste transport through ecologically sensitive area.
13.	Disruption/destruction of wild through interruption of migratory routes, disturbance of wildlife habitats, and noise related problems.	Siting to minimize impacts.
14.	Unplanned or illegal cutting or land-clearing; long-term or semi-permanent destruction of soils in cleared areas not suited for agriculture; destruction or damage of terrestrial wildlife, etc.	Prior surveys and effective management.
15.	Planned development and illegal invasion of homelands of indigenous peoples by squatters and poachers causing serious social and economic disruption.	Prior surveys and effective management.

OPTIMIZATION OF ROUTINE AND PERIODIC MAINTENANCE EXPENDITURES

The principal objective of rural road network administration is to provide adequate all-weather accessibility while minimizing user and maintenance costs. To achieve this goal, a road inventory is prepared to predict surface distress and to determine the schedule of the most effective routine and periodic maintenance activities. These activities are defined as specific work operations needed to remedy or reduce road deterioration and thus provide adequate accessibility. The organization of the work into discrete activities simplifies administration and minimizes maintenance expenditures. The prioritization and scheduling of the work activities should be implemented in a manner that minimizes the rate of surface deterioration, keeps surface roughness low, ensures an adequate pavement condition index, lowers traffic hazards, and minimizes overall maintenance expenditure and road user costs (*14*). Typical routine maintenance work includes such activities as pothole patching; cleaning and small repair work of drainage facilities such as bridges, culverts, and low-cost water crossings; vegetation control; and simple pavement repair such as cracking/rutting/edge failure. The intensity and frequency of routine maintenance work is determined from the type and severity of the road distress characteristics and the traffic projections. Periodic maintenance such as pavement strengthening is needed when routine maintenance is not effective in preventing uncontrolled pavement deterioration and to en-

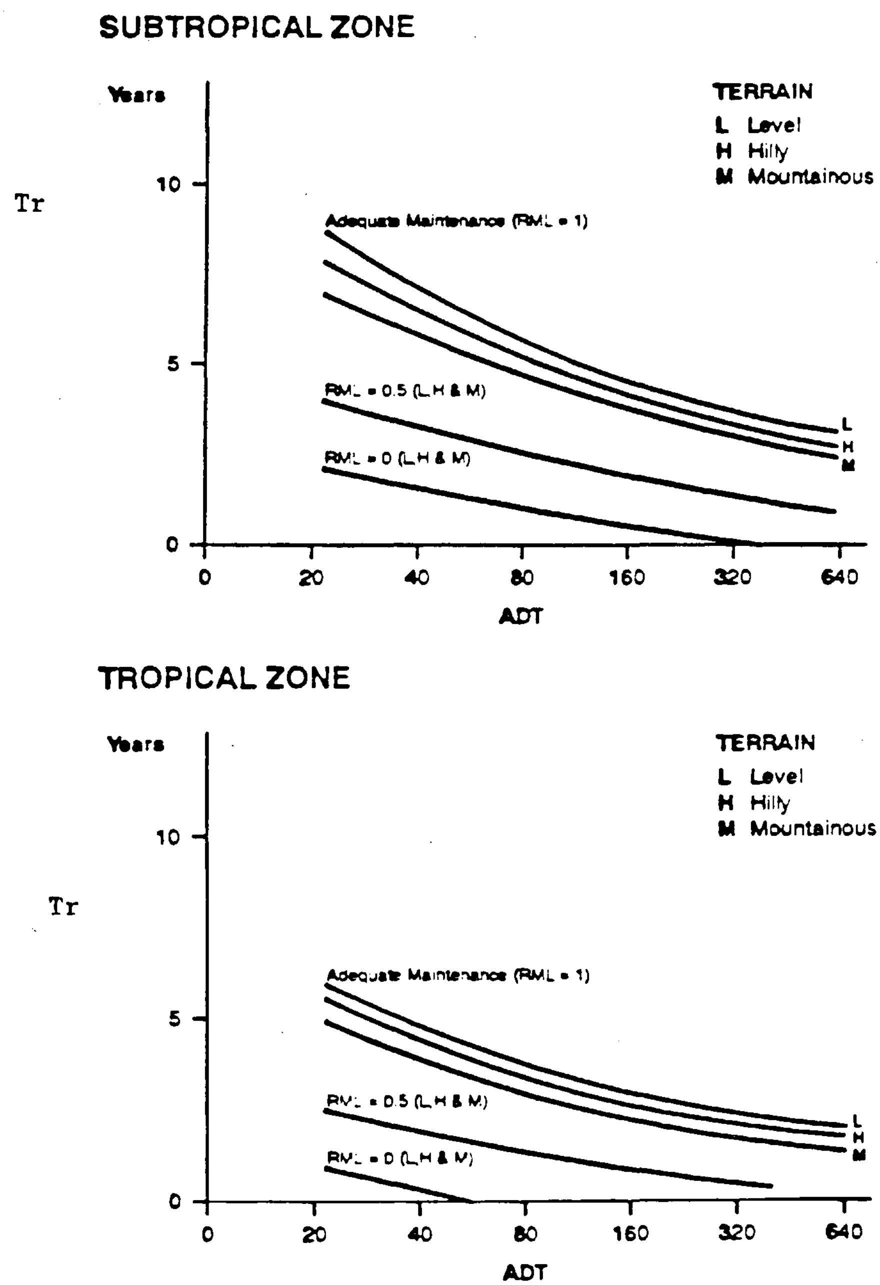

FIGURE 1 Optimum pavement rehabilitation period (Tr).

sure safe travel and low user costs. The most economical schedule of pavement strengthening is determined from quality or effectiveness of the routine maintenance work, traffic projections, and environmental and topography characteristics. The quality or effectiveness of the routine maintenance plays an important role in road conservation (*14*). The environmental classification refers to tropical, subtropical, and arid climate conditions, all of which are present in South American countries. The annual precipitation in the tropical, subtropical, and arid zones is generally 2500 to 5000, 600 to 2500, and less than 600 mm/yr, respectively.

The optimum timing of periodic pavement strengthening is the one that results in minimum road user and conservation costs during the economic lifetime of the road. Figure 1 shows the relationship between the optimal periodic pavement strengthening, traffic volume in terms of ADT, routine maintenance effectiveness level (RML), and topographical and the environmental characteristics of gravel roads (*14*). For example, when the road has ADT = 80 and is adequately maintained (RML = 1.0) in a subtropical area, pavement overlay will be needed after 5 and 6 years for mountainous and level terrains, respectively. If the road has been very poorly maintained (RML = 0.0), pavement overlay is needed every 2 years. When only approximately 50 percent of routine maintenance work activities are properly carried out, pavement overlay should be carried out every 4 years. In subtropical areas, when ADT = 80 and RML = 0, pavement rehabilitation should be carried out once a year and more often in tropical areas.

CONCLUSIONS

1. To improve the performance of existing rural road networks and to optimize investment expenditures, a socioeconomic methodology can be used to determine the most economical investment program on the basis of the costs and benefits related to levels of accessibility, traffic volumes, and the economic life of the road. The paper presents eight road improvement alternatives, of which seven are designed to provide all-weather accessibility.

2. Good road management requires continual updating of information about the road network. This is achieved by means of a road inventory that identifies each road link and evaluates both engineering characteristics and the condition of the road elements. The inventory team has to make accurate assessments of at least 150 road engineering indicators. Logic analysis expert systems can be used to assist with this process and, in particular, ensure greater uniformity and reliability in the results.

3. On low-volume road networks, transportation cost savings may not justify rural road improvement, and the methodology should include the relationship between road accessibility, agricultural production, and economic and social indicators for the rural improvement. Rural investment can only be optimized when the most economical type of road network and the complementary agricultural investments are determined simultaneously.

4. Environmental issues play an important role in the administration of low-volume roads. For each project it is necessary to identify the potential environmental impacts and to classify the proposed activity in one of four categories: beneficial to the environment, neutral to the environment, moderate potentially negative environmental impacts (but sound solutions exist for protection or mitigation), or significant potentially negative impacts. Road maintenance projects that improve surface and drainage conditions or that result in improvement of dust control may be classified as beneficial or neutral. Road improvements that require wetland replacement or erosion control may be classified in the third or fourth categories. The conclusions of the environmental analysis are implemented in the special provision of the construction documents to minimize or eliminate any damage or risk to people or the environment. A sample of potential negative impacts and the measures to mitigate them are presented in the paper.

ACKNOWLEDGMENTS

The author expresses appreciation for the support given by Alberto Paz, Christopher Ousey, and Lourdes Mouret of the Division of Transportation and Communications, Project Analysis Department, Inter-American Development Bank.

REFERENCES

1. *Guidelines for Preparation of Loan Application—Transportation and Highways.* Project Analysis Department, Inter-American Development Bank, Washington, D.C., Dec. 1982.
2. *Application of Environmental Procedures in the Transportation Sector—Guidelines.* Inter-American Development Bank, Washington, D.C., Dec. 1990.
3. Greenstein, J., and H. Bonjack. Socioeconomic Methodology for Evaluation and Upgrading of Rural Roads in Agricultural Areas of Ecuador. In *Transportation Research Record 898,* TRB, National Research Council, Washington, D.C., 1983, pp. 88–94.
4. Greenstein, J., L. Berger, and H. Bonjack. Socioeconomic Methodology for Rural Road Construction. In *Transportation Research Record 1229,* TRB, National Research Council, Washington, D.C., 1989.
5. Greenstein, J., and L. Berger. Using Expert Systems in the Inventory and Evaluation of Rural Road Networks. *Proc., Second North American Conference on Managing Pavements,* Toronto, Ontario, Canada, Nov. 1987, pp. 2316–2326.
6. Waterman, D. A. *A Guide To Expert Systems.* Addison-Wesley Publishing Company, 1986.
7. Berger, L., J. Greenstein, M. Hoffman, and J. Uzan. Practical Application of Models for Pavement Maintenance Management. *Journal of Transportation Engineering, ASCE,* Vol. 117, No. 4, July 1991.
8. Bhandari, A., and K. Tsumolsawa. *The Highway Design and Maintenance Standards Model HDM-[1] Model.* World Bank, Washington, D.C., 1987.
9. Carnemark, G., J. Biderman, and D. Bovet. *The Economic Analysis of Rural Road Projects.* Staff Working Paper 241. World Bank, Washington, D.C., 1978.
10. *Initial and Final Report Program of Technical Assistance.* World Bank, Washington, D.C.
11. *Guidelines for the Application of Environmental Procedures.* Agricultural Section, Inter-American Development Bank.
12. *Strategies and Procedures On Socio-Cultural Issues Related to the Environment.* Inter-American Development Bank.
13. Berger, L., and J. Greenstein. Design of Low Cost Bridges and Water Crossing. In *Transportation Research Record 1106,* TRB, National Research Council, Washington, D.C., 1977.
14. Greenstein, J. Optimization of the Expenditures of Maintenance and Rehabilitation of Rural Roads. *Journal of Transportation Engineering, ASCE,* Vol. 114, No. 1, pp. 40–56.

The views and opinions contained in this paper are those of the author.