6. When the cost of construction of the initial facilities and the cost of maintenance are considered with the road-user cost, a better understanding of the total transportation cost is possible. This will be the final and satisfactory answer to all highway investment questions. The Indian Government's future research on highway design and maintenance aspects will go a long way in this direction.

The results presented here are likely to be of great value to highway planners in India and in other developing countries that have similar conditions.

REFERENCES

1. Basic Road Statistics, 1975-1979. Transport Research Division, Ministry of Shipping and Transport, New Delhi, India, 1980.
2. Motor Transport Statistics, 1977-1978. Transport Research Division, Ministry of Shipping and Transport, New Delhi, India, 1980.
3. C.G. Swaminathan and L.R. Kadiyali. Road User Cost Study: A Major Research Project in Transportation in India. Presented at the Workshop on Transportation Research, School of Planning and Architecture, New Delhi, India, 1982.
4. Road User Cost Study: Draft Inception Report. Central Road Research Institute, New Delhi, India, 1977.
5. Road User Cost Study: Final Report, Vols. 1-8. Central Road Research Institute, New Delhi, India, 1982.
6. H. Hide and others. The Kenya Road Transport Cost Study: Research on Vehicle Operating Costs. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Rept. 672, 1975.
7. Empresa Brasileira de Planejamento de Transportes (GEIPOT). Research on the Interrelationships Between Costs of Highway Construction, Maintenance, and Utilisation. Brasilia, Rept. 1, Mid-Term Report, 1977.
8. L.R. Kadiyali and others. Measurement of Road Geometry and Roughness for the Road User Cost Study. Journal of the Indian Roads Congress, Vol. 42, No. 2, 1981.
9. T.D. Gillespie and others. Calibration of Response-Type Road Roughness Measuring Systems. NCHRP, Rept. 228, 1980.
10. J.C. Wambold. State of the Art of Measurement and Analysis of Road Roughness. TRB, Transportation Research Record 836, 1981, pp. 21-29.
11. W.R. Hudson. Rough Roughness: Its Elements and Measurement. TRB, Transportation Research Record 836, 1981, pp. 1-7.
12. H. Hide. Vehicle Operating Costs in the Caribbean: Results of a Survey of Vehicle Operators. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Rept. 1031, 1982.
13. L.R. Kadiyali and E. Viswanathan. Roughness Measurements for the Road User Cost Study. Central Road Research Institute, New Delhi, India, RUCS Tech. Paper 80, Fifteenth Quarterly Report, 1981.
14. L.R. Kadiyali and others. Depreciation of Vehicles. Central Road Research Institute, New Delhi, India, RUCS Tech. Paper 89, Seventeenth Quarterly Report, 1982.
15. T.V. Gopalaswami and others. Crew Cost of Vehicles. Central Road Research Institute, New Delhi, India, RUCS Tech. Paper 107, Eighteenth Quarterly Report, 1982.
16. T.V. Gopalaswami and others. Fixed Cost of Vehicles. Central Road Research Institute, New Delhi, India, RUCS Tech. Paper 108, Eighteenth Quarterly Report, 1982.

Socioeconomic Evaluation and Upgrading of Rural Roads in Agricultural Areas of Ecuador

JACOB GREENSTEIN AND HAIM BONJACK

A national socioeconomic methodology to evaluate rural roads was developed. This methodology presents the relationship among road accessibility, rainfall, drainage conditions, engineering properties of the subgrade and pavement materials, cost analysis, and agricultural benefits. A production-loss function was developed to determine the relationship between road surface conditions and losses in quality and value to agricultural products. Approximately 6000 km of rural roads along the Pacific Coast of Ecuador, 70 percent of which are dirt roads that are not usable during the wet season, were evaluated by using this methodology. A road inventory was conducted to evaluate surface conditions, soils and materials properties, drainage and structural facilities, geometric properties, and accessibility. The percentage of the cultivated area was determined together with the type of crop and the influence area of each road. Population density and the illiteracy rate within the area of influence were also determined. It was concluded that the socioeconomic evaluation of road improvement is best executed in two stages; the first, as a threshold analysis, is to determine the most economical alternative for each given traffic volume. The second stage is a complete socioeconomic analysis with determination of the internal rate of return, first-year benefit ratio, net present value, population density, and illiteracy rate. Under a total budget of U.S. $34 million, 1300 km were upgraded as a result of this study.

The provinces of El Oro, Guayas, and Los Rios, located along the Pacific Coast of Ecuador, are the biggest agricultural producers in the country. These three provinces cover 32 000 km^2 (about 11.3 percent of the total area of Ecuador). The annual agricultural exports of this region in 1978 were valued at $240 million. The population in 1979 was 3 million, approximately 35 percent of which, or 1.3 million, is the rural population.

There are approximately 6000 km, or about 1000 links, of rural roads in these three provinces. About 70 percent of these are dirt roads (Figures 1 and 2) that are not accessible during the wet season. The other 30 percent are constructed mainly of local granular-cohesive materials that have low to medium plasticity. About 55 percent of these rural roads carry less than 20 vehicles/day in both directions; 75 and 90 percent carry less than 50 and 100 vehicles/day, respectively. Only 1.5-2.0 percent of these roads carry more than 300 vehicles/day, and the recorded maximum traffic volume was 400-500 vehicles. The lack of access to markets during the wet season and the bad condition of road surfaces were found to cause significant damage to the quality of agricultural products. This also reduced production and prevented local populations from reaching needed health facilities and job and education centers.

The purpose of this study was to develop a practical socioeconomic evaluation methodology as a basis for determining investment priorities for upgrading rural roads. Local political, social, and economic demands required that the program be completed in less than one year and that it be accurate enough to be implemented into the final design and construction stage without the intermediate work of a feasibility study. Seven different types of low-volume roads, such as dirt, gravel, base, and paved roads, have been analyzed, and the relationships among road accessibility, material properties, and rainfall-drainage conditions and between road surface conditions and agricultural productivity were developed to determine the most economical and practical method of improvement.

Figure 1. Dirt road in banana-growing area of Ecuador.

Figure 2. Dirt road in coffee-growing area of Ecuador.

ENGINEERING CLASSIFICATION OF RURAL ROADS

There are seven different types of rural roads on the west coast of Ecuador (see Table 1). Type-1 roads, earth or dirt (Figures 1 and 2), are usually constructed by labor-intensive means or by use of a grader that clears a narrow strip 2.5-4.0 m wide. About 70 percent of the roads belong to this category and most of them are unusable for one to six months of the rainy season. One month with no access to markets occurs on cohesive-granular subgrade classified as A-1 to A-2-4 according to the classification of the American Association of State Highway and Transportation Officials (AASHTO). The six-month period of no access occurs on cohesive subgrades classified mainly as A-6, A-7-5, and A-7-6, which have a plastic index of more than 12 percent. The traffic loading that this subgrade road can carry before grading is required varies according to the subgrade California bearing ratio (CBR) (1). Roads with a subgrade CBR of 4 and 7 percent can carry 400 and 3000 equivalent axle loads (EALs) of 8200 kg each. Failure is defined as a rutting value of 10-13 cm (1).

Road types 2 and 3 are compacted, silty-sand subgrade roads of 4.0 and 6.0 m, respectively. The thickness of the compacted subgrade varies between 10 and 30 cm; the design CBR varies between 7 and 9 percent. The loading that this type of pavement can carry before reconstruction is needed varies between 3000 and 11 000 EALs for type-2 and 6000-22 000 EALs for type-3 roads, respectively (1). Reconstruction is done when rutting depth is about 10 cm, and it includes grading, resurfacing, wetting, and compaction. The minimum thickness of the compacted soil is 8 cm.

Types 4 and 5, which include gravel or laterite roads, are respectively 4.0 and 6.0 m wide. The design CBR of the subbase pavement is 20-40 percent, and the thickness varies between 12.5 and 35.0 cm according to the subgrade CBR and the design traffic loading, which is 24 000 and 48 000 EALs for type-4

Table 1. Engineering properties of rural roads in Ecuador.

	Road Type													
	7		6		5		4		3		2		1	
	Terrain[a]													
Property	L	H	L	H	L	H	L	H	L	H	L	H	L	H
Design speed (km/h)	60	50	60	50	50	35	50	35	50	35	50	35	30	20
Minimum horizontal radius (m)	120	80	120	80	80	40	80	40	80	40	80	40	25	12
Pavement width (m)	6.0		6.0		6.0		4.0		6.0		4.0		3.0-4.0	
Shoulder width (m)	2 x 0.6		2 x 0.6		-		-		-		-		-	
Pavement materials	Base, CBR ≤ 80 percent, DBST		Base, CBR ≥ 60 percent		Subbase, CBR > 20 percent		Subbase, CBR > 20 percent		Compacted subgrade, CBR 7-9 percent		Compacted subgrade, CBR 7-9 percent		Natural subgrade, CBR 4-7 percent	

[a]L = level; H = hilly; DBST = double bituminous surface treatment.

and type-5 roads, respectively. The design criterion for these roads is a rut depth of 8 cm (2).

Type-6 and type-7 roads have a base 7.20 m wide. Type 6 has no asphalt surface treatment; type 7 does. Their pavement thickness varies between 12.5 and 40.0 cm. The CBR design value of the base pavement is 60-80 percent; the design traffic loading is 200 000 EALs and 400 000 EALs, respectively. The design criterion is a rut depth of 5 cm (2).

SCREENING METHODOLOGY OF THRESHOLD ANALYSIS

A precise economic evaluation of rural roads requires an analysis of all the possible improvement alternatives. In other words, for each dirt road classified as type 1 there are six alternatives of improvement to road types 2, 3, 4, 5, 6, and 7, and all of these alternatives should be analyzed in order to determine the most economical one. The implementation of such methodology in Ecuador requires the analysis of about 5000 alternatives. This is a costly, time-consuming, and impractical process for a single year's planning study of 6000 km of roadways. The economic evaluation of road improvement is therefore best executed in two stages: the first, as a threshold analysis, is to determine the most economical alternative for each given traffic volume. The second stage is a complete economic analysis with determination of the internal rate of return (IRR), first-year benefit ratio (FYBR), and net present value (NPV). In the threshold stage, the relationship between the minimum economic transportation cost and the volume of traffic is analyzed for each of the seven road types. This cost includes construction, maintenance, reconstruction, and vehicle operating costs for 15 years of service. Figure 3 presents this relation and enables determination of (a) the minimum economic transportation cost for any given traffic volume, (b) what road this cost is related to, or (c) what the most economical road-improvement alternative is. According to the conclusion of Figure 3, for an estimated traffic volume of 50-100 vehicles/day, the most economical road type in level terrain is the one-lane subbase (type-4) road. For daily traffic of less than 50 vehicles/day, the type-1 dirt road is the most economical alternative. The conclusions of the threshold analysis are summarized below and the most economical alternative for each road's traffic volume and topography is assigned.

Road Type (minimum transportation cost)	Traffic Volume (vehicles/day)	
	Level Terrain	Hilly Terrain
1	5-50	5-60
4	51-100	61-150
5	101-200	151-200
6	201-250	201-300
7	250+	300+

According to the tabulation above, when the traffic volume is less than 250 or 300 vehicles/day, paved roads are not economical for level or hilly terrain, and in Ecuador dirt and gravel roads are constructed for this volume of traffic.

INVENTORY AND ROAD EVALUATION

An inventory of the existing rural roads is used to identify each separate link of the system and to evaluate its engineering properties such as geometry, soils, pavement and surface condition, drainage facilities, bridges, and distance to available material sources. This information is used to classify each road and to estimate the amount of work necessary to improve it to any given higher standard. In Ecuador this inventory was broadened to include an evaluation of how long a rural road is out of use during the rainy season. This information was then incorporated in the agricultural-economic evaluation, which is presented later in this paper. The accessibility analysis presents the relationship among soils and materials classification, drainage conditions, and the months that the road is unusable in the rainy season. This relation as determined on the west coast of Ecuador is presented in Table 2.

For example, a dirt road (type 1) with a clay surface, which is classified as A-6 according to the AASHTO classification, has poor drainage conditions and cannot be used during six months of the rainy

Figure 3. Relation between total transportation cost and traffic volume.

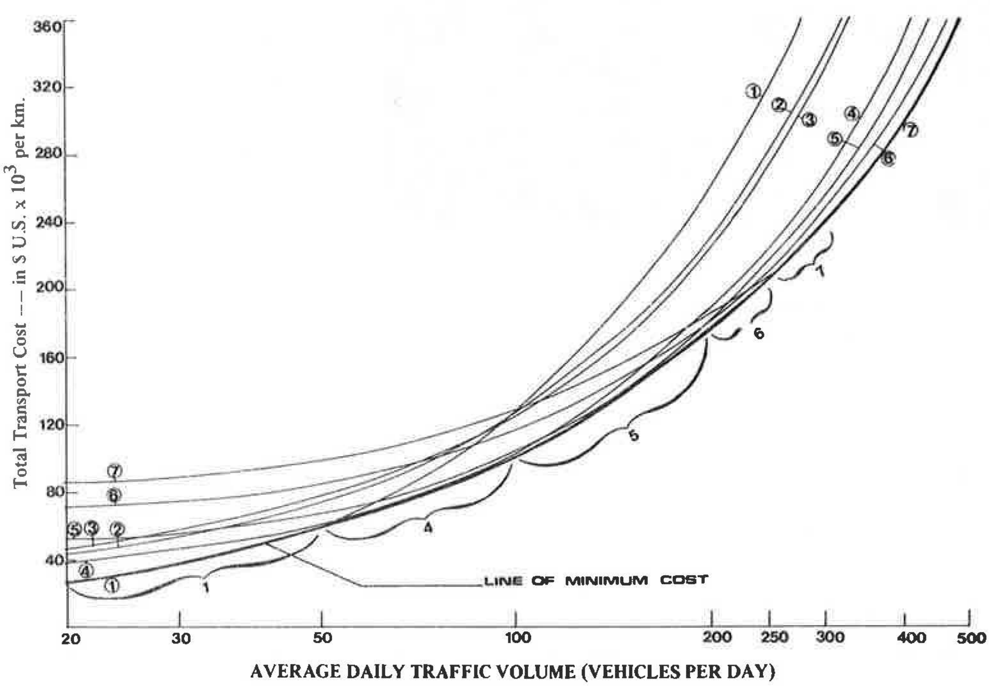

Table 2. Relation between soils or materials classification and months without accessibility.

	Months Without Accessibility						
	Road Type						
	1			2 and 3			4, 5, 6, 7
	AASHTO Classification						
Drainage Condition	A-4, A-6, A-7-5, A-7-6	A-2-6, A-2-7	A-1, A-2-4	A-4	A-2-6, A-2-7	A-1, A-2-4	A-1, A-2-4
Good	4	2	1	2	1	-	-
Poor	6	4	3	3	2	1	-

Table 3. Construction cost of rural roads in Ecuador.

		1979 Cost ($000s/km)						
		Road Type						
Type of Cost	Terrain	1	2	3	4	5	6	7
Economic	Level	0.2	12.8	15.62	16.2	20.2	34.7	42.9
	Hilly	0.2	24.4	27.8	28.6	33.6	54.8	62.2
Financial	Level	0.2	14.2	17.1	17.8	21.9	37.5	45.9
	Hilly	0.2	26.1	29.5	30.5	35.7	59.5	68.0
Foreign exchange	Level	0.1	5.9	7.3	7.6	9.6	16.1	18.9
	Hilly	0.1	10.8	12.5	12.7	15.2	25.7	28.6

Table 4. Construction cost of rural road bridges in Ecuador.

	1979 Cost ($000s/lineal m)[a]		
Type of Cost	<30	31-60	>61
Deck only			
Economic	0.68	0.64	0.60
Financial	0.78	0.70	0.66
Foreign exchange	0.28	0.24	0.22
Entire bridge			
Economic	1.54	1.26	1.00
Financial	1.72	1.40	1.10
Foreign exchange	0.60	0.48	0.38

[a]One-lane bridge, 5.0-m width.

season. Improvement of the drainage condition can cut this period to four months, and with the use of a sandy material classified as A-2-4, accessibility can be improved so that only one month of the year would be lost instead of six.

COST-ANALYSIS METHODOLOGY

Unit-Cost Analysis

One of the main conclusions obtained in this study is that a precise unit-cost analysis is needed to achieve an accurate cost estimate that will be in the range of ±15 percent of the final construction cost. The unit-cost analysis was carried out in terms of both the economic and financial costs. The financial costs were broken down into a unit-cost study that includes the following calculations and analysis (all costs are expressed in U.S. dollars):

1. A calculation was done of the hourly operational costs of equipment used to construct rural roads, such as tractors, graders, trucks, compactors, vibrators, compressors, and pumps. These hourly operational costs include both property costs (amortization, interest, insurance, and taxes) and direct costs for operation (fuel, lubricants, tires, repairs, and wages). The detailed hourly costs have been given by Greenstein and Negrete (3). For instance, the total hourly operation costs of a Caterpillar tractor D-6 in 1979 were $32.20 (economic), $35.40 (finance), and $17.40 (in foreign exchange).
2. A detailed equipment efficiency analysis was made for each type of equipment. By using the local experience, the most economical and practical combination of construction equipment was assigned to each work item and its efficiency was then determined (3). For example, the best combination of equipment required to excavate 1000 m^3 is tractor D-8 (3.5 h), tractor D-7 (3.0 h), tractor D-6 (2.40 h), and grader (0.5 h). A similar analysis was done for all other earthwork items, pavement and drainage work, materials, etc.
3. An analysis was made of manpower costs for each work item. For example, to excavate 100 m of a drainage ditch required a foreman for 8 h at a wage of $1.70/h and unskilled workers for 144 h at a wage of $0.88/h. The direct cost of construction for this ditch, therefore, was $140.32.
4. An analysis of overhead cost and profit was completed that included administrative and office expenses, technical advice, supervision, survey and laboratory equipment, mobilization of construction equipment, maintenance and operation of construction camps, food allowance, local taxes, etc. In Ecuador, the overhead cost in 1979 was 40 percent of the direct cost and the profit was 15 percent.

Construction Costs

The road evaluation carried out during the inventory was interpreted to determine the engineering value of each road element, that is, earthwork, pavement, drainage, and structure. These data were then used to calculate the work quantities required to improve the existing road to the alternative road, which was determined according to the results of the threshold analysis. Knowing the quantities and unit costs permits calculation of construction costs. Table 3 presents the construction cost of the seven types of rural roads in Ecuador. It should be pointed out that the construction of type-1 road is carried out by means of a tractor or grader that cleans and clears, within 3-4 m of width, only about 30 cm of the upper surface. In Ecuador, 4-5 km of this road can be constructed per day at a cost of about $200/km. Road type 4 is the most economical all-weather road and its average economic and financial construction costs are $16 200/km and $17 800/km, respectively, and the required amount in foreign exchange is $7600/km. A foreign-exchange analysis is required by the World Bank, which finances this part of the budget; the Government of Ecuador finances the cost in local currency.

Construction costs of low-cost bridges for rural roads in Ecuador are given in Table 4. These are one-lane bridges about 5.0 m wide. For example, the financial cost of a bridge that has a 30-m span is $1720/lineal m, and the cost of its deck is $780/m; $600 of the total cost is in foreign exchange.

Maintenance and Reconstruction Costs

The maintenance and reconstruction cost analysis includes both the work quantities and the results of the unit-cost analysis. The work quantities necessary to maintain and reconstruct the roads and the unit prices determined previously (1-3) were used to calculate the maintenance costs shown in Table 5. According to Table 5, $200, $1000, and $2700 were needed in 1979 to maintain 1 km of type-1, type-4, and type-7 road, respectively, in level terrain.

Table 5. Cost of maintenance and reconstruction of rural roads in Ecuador.

Road Type	Pavement Thickness (cm)	Maintenance Cost ($000s/year) Terrain Level	Hilly	Reconstruction Cost ($000s/operation)
1	-	0.2	0.2	0.2
2	20, local soil, CBR 7-9 percent	1.0	1.1	1.0
3	20, local soil, CBR 7-9 percent	1.1	1.2	1.4
4	15, subbase, CBR >20 percent	1.0	1.1	3.7
5	15, subbase, CBR >20 percent	1.1	1.3	5.4
6	12.5, base, CBR >60 percent	1.7	2.0	7.4
7	14, base, CBR >80 percent, asphalt	2.7	2.9	14.1

Table 6. Agricultural loss coefficient ($_1D_i$) versus months without access to markets.

Type of Crop	Months Without Access per Year 1	2	3	4	5
Cacao	0.007	0.014	0.020	0.027	0.027
Coffee	0.006	0.012	0.018	0.024	0.027
Corn	0.013	0.025	0.030	0.050	0.050
Rice (traditional method)	0.0	0.0	0.0	0.010	0.060
Rice (semitechnical method)	0.013	0.025	0.030	0.060	0.110
Cotton	0.030	0.060	0.090	0.120	0.150

The pavement reconstruction is carried out when the rutting depth is 5-8 cm. Table 5 also presents these costs, which were $200, $3700, and $14 100 for types 1, 4, and 7, respectively. In this example, the reconstruction work was carried out with 15 cm of subbase material for road type 4 and 14 cm of base and asphalt surface treatment for road type 7. The design CBR of the subbase and base was 20 percent for the type-4 road and 80 percent for the type-7 road.

Vehicle Operating Costs

The detailed analysis of vehicle operating costs (VOC) carried out in Ecuador is given in the study performed for the Ministry of Public Works of Ecuador (3). In this analysis, the recommendations [given elsewhere (4,5)] were adjusted for the representative vehicles and the seven rural road types defined in Table 1. The representative vehicles were truck, bus, and pickup, or about 93 percent of the existing means of transportation on the west coast of Ecuador. The economic VOC of these vehicles in optimum conditions (3-5) were $0.41, $0.25, and $0.14/km for truck, bus, and pickup, respectively.

ANALYSIS OF AGRICULTURAL BENEFITS OBTAINED BY RURAL ROAD IMPROVEMENT

The economic impact of penetration roads in agricultural areas is generally implemented by the producer-surplus approach (6). According to this approach, a large portion of the benefits is obtained by increasing the cultivated areas as the result of introducing new roads. This is not the case in Ecuador, since the areas that any new roads are likely to influence are already cultivated. The poor condition of Ecuador's roads is the main reason for losses in both production quantity and quality. The losses of quantity are caused mainly by lack of accessibility to markets during the rainy season; product quality damage is caused by the bad surface conditions of low-standard road types 1, 2, and 3.

Lack of Accessibility to Markets

When a road in an agricultural area cannot be used during the rainy season, the following losses, damages, or disturbances occur:

1. Impossibility of tranferring the crops to the local market;
2. Rise of transport costs when other modes of transportation, such as waterways, animals, or people, are used as substitutes;
3. Insufficient technical assistance when necessary; or
4. Inefficient seeding or harvesting during the rainy season.

The following relationship among the agricultural losses, the cultivated area, the type of crop, and the annual production was derived:

$$P_{aj} = \sum_i (A_i B_i C_i \, {}_1D_i/100) \quad (1)$$

where

P_{aj} = agricultural loss (U.S. dollars) due to road j's lack of accessibility during rainy season;

A_i = total cultivated area the production of which can be transferred only along analyzed road j; A_i includes agricultural area along road j and other cultivated areas along other roads the production of which can be transferred to the local market only along road j; on the west coast of Ecuador the cultivated area along road j, determined approximately within the distance of 2.5 km from each side of the road, is defined as the area of influence;

B_i = percentage of agricultural area cultivated with product i, which is cacao, coffee, corn, rice, and cotton;

C_i = annual value of product (U.S. dollars per hectare); for example, C_i in 1979 was $340/ha and $475/ha for cacao and coffee, respectively;

${}_1D_i$ = agricultural loss coefficient of crop type i; ${}_1D_i$ varies with the number of months that the road cannot be used and the type of crop (see Table 6). For example, when a road cannot be used during one and five months/year in a cacao agricultural area, ${}_1D_i$ equals 0.007 and 0.027, respectively.

The following example demonstrates the implementation of Equation 1: A 4-km road, type 2, with a cultivated area of influence of about 20 ha is used to transfer the production of about 100 ha of cultivated area to the nearest market. The pavement along the road is a silty-sand material, AASHTO classification A-2-6. The drainage conditions are poor. Of the total agricultural area, 60 and 40 percent are cultivated with cacao and coffee, respectively. In this case, according to Table 2, this road cannot be used for two months; therefore, according to Table 6, ${}_1D_i$ equals 0.014 and 0.012 for the cacao and the coffee. The annual value of these products in 1979 was C_i = \$340/ha for cacao and C_i = \$475/ha for coffee. Thus, the estimated loss due to lack of accessibility is

P_{aj} = \$120 (\$0.6 x \$0.340 x \$0.014 + \$0.4 x \$475 x \$0.012) = \$616/year, or about \$150/(km•year).

Damage to Agricultural Products

Some agricultural products, such as bananas and tomatoes, suffer significant damage when transported over roads with a poor surface condition. This type of damage (or quality loss) was analyzed in Ecuador and the following model developed:

$$P_{dj} = L_j \sum_i (C_i\, {}_2D_i/100)\,[(A_j B_i/2) + A_s B_i] \quad (2)$$

where

- P_{dj} = agricultural damage value (U.S. dollars) due to the poor surface condition of road j;
- i = perishable products, which are sensitive to the conditions of the road surface; in this study i = 2 and includes bananas and tomatoes;
- A_j = cultivated area along analyzed road j;
- A_s = cultivated areas along other feeder or access roads that must use road j to transport produce to local markets;
- B_i = percentage of cultivated areas with the product i, bananas or tomatoes;
- C_i = annual value per hectare;
- L_j = length of road j; and
- ${}_2D_i$ = agricultural damage factor per kilometer.

Values of ${}_2D_i$ are presented below:

Type of Crop	Type of Road	Damage Factor ${}_2D_i$
Banana	1	0.0100
(i = 1)	2,3	0.005
	4-7	0.000
Tomato	1	0.005
(i = 2)	2,3	0.003
	4-7	0.000

${}_2D_i$ varies with road and crop type; one of the conclusions of this study is that along an all-weather road (types 4-7), the damage to the agricultural product can be disregarded.

The following representative example demonstrates the implementation of Equation 2. A dirt road (L_j = 4 km), type 1, is used for transportation to a local market of A = 20 ha plus A = 70 ha, of which 90 percent is bananas and 10 percent is tomatoes. The agricultural damage factors are 0.01 and 0.05 for these products, respectively. The average annual value (C_i) of producing bananas and tomatoes in 1979 in Ecuador was \$1590/ha and \$4000/ha, respectively. In this case, the total estimated damage is

P = \$41 590 x \$0.01 (\$20/\$2 + \$70 x \$0.9) + \$4000 x \$0.005 x \$70 x \$0.1 = \$5203 or about \$1300/(km•year).

SOCIOECONOMIC ANALYSIS

Economic Analysis

The economic analysis includes the calculation of NPV, IRR, and FYBR. These economic parameters were calculated for a 17-year period for each road. The net-benefits stream was defined as follows:

$$B_t = (M_{0t} - M_{it}) - C_t + (R_{0t} - R_{it}) + P_{ajt} + (O_{0t} - O_{it}) \quad (3)$$

where

- B_t = net benefits in year t;
- M_{0t} = annual maintenance costs required to maintain existing road in year t;
- M_{it} = annual maintenance costs required to maintain proposed improved road in year t;
- R_{0t} = annual reconstruction costs required to reconstruct pavement of existing road in year t;
- R_{it} = annual reconstruction costs required to reconstruct pavement of proposed improved road in year t;
- C_t = construction cost required to improve an existing road to a higher standard in year t;
- P_{ajt} = agricultural benefits achieved in year t by improving accessibility of an existing dry-season road, type 1, 2, or 3, to an all-weather road (see Equation 1);
- P_{djt} = agricultural benefits achieved in year t by cutting damage and quality loss to products due to road improvement (see Equation 2);
- O_{0t} = VOC of existing road in year t; and
- O_{it} = VOC of proposed improved road in year t.

A sample of the results of the economic analysis is given in Table 7, which presents the values of the three economic parameters for four representative rural roads in the province of El Oro. For example, the existing 2.1 km of road 3055-0 is type 3 and it is proposed that it be improved to a type-4 all-weather road. The estimated construction cost of this improvement is \$26 000. The estimated benefits of this improvement in the year 1982 are \$23 800 in agriculture and \$2200 in savings in VOC. The IRR is 101.2 percent and the FYBR is 101.2 percent. The NPV calculated for a discount rate of 10 percent is \$187 000. On road 3057-1, the IRR is 8.2 percent and the benefits are only in VOC savings.

Social Considerations

The government of Ecuador and the International Bank for Reconstruction and Development specify that the results of the economic evaluation must be analyzed together with the social factors.

The only social data available in Ecuador that can be analyzed during a limited period of one year are population density and rate of illiteracy. It is obvious that the higher the population density, the greater is the need for transportation to local markets, public institutions, health and educational facilities, and commercial centers. This is to say that for any given investment, the social benefits to be achieved by rural road improvements will be greater for the higher population density that will be served. The population index (PI) defined in Equation 4 represents this social factor:

PI = population in the road's area of influence divided by construction cost in thousands of sucres (4)

The local currency in Ecuador is the sucre, and in 1979, U.S. \$1 = 25 S/. The use of Equation 4 is as follows. The population within the area of influence of road 3025-0 is 213 (see Table 8). The construction cost was \$81 000 = 2 027 500 S/. Thus, PI = (213/2 027 500)100 = 10 500 or 10.5.

Table 7. Sample results of economic analysis, Province of El Oro.

Road No.	Length (km)	Road Type Existing	Road Type Improved	IRR (%)	FYBR (%)	NPV (10 percent) ($)	Construction Cost (1981) ($000s)	Agricultural Benefits (1982) ($000s)	Saving of VOC (1982) ($000s)
3055-0	2.1	3	4	104.6	101.2	187.0	26.0	23.8	2.2
3025-0	5.0	1	4	33.7	32.5	143.9	81.1	17.9	13.5
3057-1	1.5	4	5	8.2	36.5	1.9	20.6	0.0	0.74
3036-0	1.7	2	4	16.2	13.3	6.8	17.3	1.2	1.1

Table 8. Socioeconomic order of priorities for rural road improvement.

Order of Priorities	Road No.	Length (km)	Road Type Existing	Road Type Improved	Population	IRR (%)	Population Index	Education Index	Socioeconomic Priority Index
1	3055-0	2.1	3	4	216	104.6	33.2	6.5	81.2
40	3025-0	5.0	1	4	213	33.7	10.5	1.8	26.1
44	3057-1	1.5	4	5	403	8.2	78.2	15.3	24.5
70	3036-0	1.7	2	4	0	16.1	0.0	0.0	11.3

Another social index used in this study is the education index (EI) defined in Equation 5:

$$EI = (RI)(PI) \quad (5)$$

where RI, as a percentage, is the rate of illiteracy of the population in the areas of influence of rural roads. This percentage was determined for the area of influence of each rural road in this study. For example, RI = 19.6 percent in the area of influence of roads 3055-0 and 3257-1 and RI = 17.1 percent for 3025-0. Thus, for road 3025-0, EI = (0.171)(10.5) = 1.8.

In order to analyze the economic index together with the social indices, the following empirical socioeconomic priority index (SEPI) was derived:

$$SEPI = 0.700(IRR) + 0.225(PI) + 0.075(EI) \quad (6)$$

The interpretation of Equation 6 is that SEPI is composed of 70 percent economic consideration and 30 percent social consideration. This empirical relationship between the economic and social factors was determined by the government of Ecuador to present the local priorities. Table 8 shows that road 3055-0, which has the highest IRR (104.6 percent) and high population density (103 inhabitants/km), ranks first with SEPI = 81.2. Road 3025 has a lower IRR (33.7 percent) and a population of 213/5 = 43 inhabitants/km. The SEPI, 26.1 for this road, therefore is ranked in the 40th place. Roads 3057-1 and 3036-0 do have an IRR equal to 8.2 percent and 16.1 percent, respectively. Nevertheless, they are in 44th and 70th place priorities, since the population density along road 3036 is zero.

The SEPI presented in Equation 6 was implemented to determine the priorities of the financial investment of upgrading 1300 km of rural roads. A total budget of $34 million was assigned for this purpose. Of this amount, $19 million was in local currency and $15 million in foreign exchange.

CONCLUSIONS

Three main conclusions are derived from this study:

1. The relationship among the accessibility, road type, material properties, rainfall, and drainage conditions was analyzed for a rural-road improvement project in Ecuador. A production-loss function was developed to determine the relationship between road improvements and agricultural benefits. The implementation of this methodology to evaluate 6000 km of rural roads shows that approximately 1300 km were justified for improvement under a total budget of $34 million.
2. The socioeconomic factors analyzed in this study are the IRR, FYBR, NPV, population density, and illiteracy rate. Road improvements increase agricultural productivity, reduce damage to product quality, and cut VOC. Improving a dirt road that cannot be used during the rainy season to an all-weather gravel or paved road significantly cuts agricultural losses caused by the inaccessibility to markets and poor road-surface conditions.
3. In order to achieve an accurate cost estimate, a precise unit-cost analysis is required. This would include calculations of hourly operating cost for construction equipment, an equipment efficiency analysis, a manpower analysis including cost per work item completed, and analysis of overhead costs.

REFERENCES

1. J. Greenstein and M. Livneh. Pavement Design of Unsurfaced Roads. TRB, Transportation Research Record 827, 1981, pp. 21-26.
2. J. Greenstein and M. Livneh. Thickness Design of Low-Volume Roads. TRB, Special Rept. 702, 1979.
3. J. Greenstein and J.G. Negrete. Estudio de Caminos Vecinales-República del Ecuador. World Bank, Washington, DC, 1979.
4. J. De Weille Bank. Quantification of Road User Savings. Johns Hopkins Univ. Press, Baltimore, MD, Staff Occasional Paper 2, 1966.
5. R. Winfrey. Economic Analysis for Highways. International Text Book Company, Scranton, PA, 1969.
6. G. Carnemark, J. Biderman, and D. Bovet. The Economic Analysis of Rural Road Projects. World Bank, Washington, DC, Staff Working Paper 241, 1978.