Socioeconomic Methodology for Rural Road Construction

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In many South American countries, such as Ecuador, Peru, and Bolivia, rural development has been held back by a lack of accessibility to many potentially rich agricultural areas. As a result, these areas are now being used for subsistence farming only rather than for more mechanized farms that could produce substantial amounts of agricultural surplus. It is apparent that road improvement could increase agricultural production and substantially reduce the user costs because the better road surfaces would encourage the use of motorized vehicles rather than animals or river boats. The better economic returns possible from the existing land would lead to an increase in the area under cultivation and eliminate the potential loss from crop deterioration resulting from a lack of access during harvest season or damage to fragile crops because of rough road surfaces. The economic analysis requires not only a determination of the costs and benefits, but an evaluation of such economic indicators as net present value, first year rate of return or internal rate of return, and optimum schedule for construction. The economic indicators, when evaluated jointly with such social factors as population density and level of education, are used to predetermine both the socioeconomic justification and the priorities for rural road construction.

Pacific Rim countries of South America, such as Ecuador, Peru, and Bolivia have three major climatic zones: tropical or mountainous with subtropical conditions, tropical or mountainous with arid conditions, and semiarid zones. In general, the subtropical zones, including the west coast of Ecuador, possess the richest agricultural areas and produce such export commodities as bananas, coffee, cocoa, rice, vegetables, and shrimp. However, the economic growth of these areas has been substantially hindered by poor accessibility, which has substantially increased the vehicle operating costs and traffic hazards.

A socioeconomic methodology that examines the relationships between road accessibility, agricultural production, and economic and social indicators for rural improvement has been developed that evaluates the benefits of investments from road construction in such rural areas. Socioeconomic analysis of road construction for rich agricultural areas is best executed in two stages (*1,2*). The first stage, which is a threshold analysis, determines the most economical alternative for each given traffic volume. The second stage is the socioeconomic analysis that evaluates the benefits obtained from reduced transportation costs and reduced losses in the value of agricultural products being transported to local or international markets. Although the investments are made only in the road sector, other benefits derived from better accessibility include a reduction in the rate of illiteracy and a resettlement of the population closer to good transportation facilities. Most of the rural areas in South America are not as rich as the western provinces of Ecuador (*1,2*), and, consequently, they require additional investments to justify road construction now (*2,3*). These complementary investments in rural agriculture, when combined with the investment for road construction, can often generate sufficient economic benefits to justify the entire program.

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The authors' experience in road planning in the developing world indicates that this concept of socioeconomic evaluation can be successfully used in virtually every tropical, subtropical, or arid zone that possesses a potential for agricultural growth. This specific methodology was used in 1986 for the planning and construction of over 1,600 km of rural roads in the mountainous and eastern Amazonas regions of Ecuador.

ENGINEERING CLASSIFICATIONS OF RURAL ROADS

In the Pacific Rim countries of South America, nine main types of rural roads have been identified (Table 1). Type 1 is designated for dirt roads built with limited engineering input using either labor-intensive methods or limited use of a motorgrader. During the rainy season, these dirt roads are frequently impassable from 1 to 6 months, depending on whether they are in semiarid or subtropical areas, and also depending on whether good or poor drainage conditions exist. The life expectancy of these earth roads is likewise a function of the surface California bearing ratio (CBR). Prior experience has demonstrated that roads with a subgrade CBR of 4 to 7 can carry, respectively, 400 to 3,000 equivalent standard axle loads (ESALs) of 8,200 kg. Failure of these earth roads is defined as rutting to a depth of 10 to 15 cm (*4*).

Road Types 2 and 3 are composed of compacted silty sand constructed to widths of from 4 to 6 m, respectively. The thickness of the surface course on these roads varies between 10 and 30 cm, and the design CBR varies from 7 to 9. These roads are capable of carrying between 3,000 to 11,000 ESALs for Type 2 roads and approximately 5,000 to 20,000 ESALs for Type 3 roads (*4*).

Road Types 4 and 5 are constructed with a gravel or laterite surface, from 12 to 35 cm thick. The roads are built 4 to 6 m wide, respectively, are usually designed to carry between 25,000 to 50,000 ESALs, and have a life expectancy of approximately 7 years before rehabilitation (*3, 4*).

Roads 4E and 5E are stone roads (*empedrado* in Spanish) requiring minimum maintenance. These roads have a life expectancy of from 20 to 30 years before strengthening or

TABLE 1 BASIC ENGINEERING PROPERTIES OF RURAL ROADS

Property	Road Type 7 L	7 M	6 L	6 M	5 L	5 M	5E L	5E M	4E L	4E M	4 L	4 M	3 L	3 M	2 L	2 M	1 L	1 M
Design speed (km/hr)	60	40	60	40	50	25	50	25	50	25	50	25	50	25	50	30	30	20
Minimum horizontal radius (m)	120	50	120	50	80	30	80	30	80	30	80	30	80	30	80	30	25	12
Pavement width (m)	6.0		6.0		6.0		5.0-6.0		3.0-4.0		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, DBST		Base, CBR >60		Subbase CBR>20		Stone		Stone		Subbase CBR>20		Compacted subgrade, CBR 7-9		Compacted subgrade, CBR 7-9		Natural subgrade, CBR 4-7	

Terrain[a]

[a] L = level; DBST = double bituminous surface treatment; M = mountainous.

rehabilitation is necessary. They vary in width from 3 to 4 m for Type 4E and 5 to 6 m for Type 5E (Table 1).

Road Types 6 and 7 are normally about 7.2 m wide with Type 6 being free of asphalt surfacing and Type 7 with an asphaltic surface treatment. Types 6 and 7 are designed to carry from 200,000 to 400,000 ESALs and have a design life of approximately 10 years (*2,3,5*). For Type 6 and 7 roads, pavement failure is defined as rut depth of 5 to 7 cm for road Types 7 and 6, respectively.

PRINCIPLES OF THE ECONOMIC METHODOLOGY

The major conclusion reached from the rural road studies carried out in Ecuador between 1984 and 1986 (*2,3*) was that the optimization of rural investment can only be obtained when the most economic type of roadway and the optimized complementary agricultural investments are both made simultaneously. Benefits achieved are as follows:

- Reduced transport costs by the substitution of economical motor vehicles replacing animal transport or river boats;
- More effective use of agricultural land by converting it from subsistence farming to commercial production;
- Increased yield per unit area through the introduction of more modern farming equipment, fertilizers, pesticides, and other technical assistance;
- Raising of crops with much higher economic value because perishables for the domestic market can be grown in place of long-life more stable crops; and
- Because of all-weather accessibility, ability to harvest the crops when they are ready for market, regardless of the weather conditions at that season of the year.

When these factors are able to generate more income and benefits than the total expenditures required during the lifetime of the road, or when the first year rate of return and other economic indicators indicate returns exceeding 12 percent, the road investment is normally considered justified by international financing agencies.

DETERMINATION OF MOST ECONOMIC TYPE OF ROAD

The least-cost type of road for each level of traffic is determined by analyzing the relationship between the total transportation cost and the traffic volume (*1–3*). The total transportation cost for a given road includes construction, maintenance, and reconstruction expenditures and vehicle operating cost (VOC) during the economic lifetime of the road, which is normally 15 to 20 years (*2,3*). During this service period, most of the benefits of the complementary agricultural investment can be developed and the construction justified (*2,3*).

The conclusions of this road screening or threshold analysis (*1–3*) are summarized as follows, and the engineering properties of these roads are shown in Table 1.

Road Type (min. transportation cost)	*Traffic Volume (vehicles per day)*
1	5–25
4 or 4E	26–100
5 or 5E	101–200
7	over 200

According to these tabulations, when the traffic volume is less than 200 vehicles per day, paved roads are not feasible and gravel or stone roads are constructed to provide all-weather accessibility.

ANALYSIS OF ECONOMIC TRANSPORTATION EXPENDITURES

The main objective of road planning is to determine the optimum level of construction and maintenance effort that will result in the lowest possible transportation expenditures during the lifetime of the road. In order to properly determine transportation expenditures it is necessary to carry out a precise unit cost analysis of the construction, maintenance, reconstruction, and vehicle operating costs (*1–3*). The unit cost analysis was carried out in both economic and financial terms to eliminate any cost distortions resulting from taxation or subsidies.

Construction Costs

The construction cost of a new road depends on such factors as topography and climate, availability of construction materials, and availability and cost of equipment and local labor. Table 2 presents representative economic costs or rural roads in Ecuador per km in 1985 and 1986. For example, the economic construction cost of a gravel road (Type 4) is $50,000, $65,000, and $105,000 for level, hilly, and mountainous terrain, respectively. The financial cost in Ecuador in 1985 was approximately 10 to 12 percent less, because of subsidies in petroleum products. The portion of foreign exchange is approximately 30 to 40 percent of the total cost. Economic construction costs of bridges for rural roads in Ecuador in 1985 and 1986 are given in Table 3 (*3,6*). These are one-lane solid concrete bridges 5.0 m wide.

Maintenance and Reconstruction Costs

The maintenance and reconstruction cost analysis includes both the determination of the annual periodical and emergency work quantities for each maintenance activity and the results of the unit cost analysis. The work quantities necessary to maintain and reconstruct the roads and the unit prices used to calculate the maintenance and reconstruction costs are shown in Table 4 (*7*).

VOC

A detailed analysis of VOC is usually needed to justify investment in rural road construction or upgrading (*1–3*). For this type of analysis in South America, the recommendations given elsewhere (*8,9*) were adjusted for the representative vehicles and the nine rural road types defined in Table 1. The economic VOCs of these representative vehicles in optimum road conditions were $0.40, $0.35, and $0.20/km for truck, bus, and pickup, respectively (*1–3*).

COMPLEMENTARY RURAL INVESTMENT COSTS

As previously mentioned, rural road construction can be justified economically in rich agricultural areas without the need for complementary rural investments (*1,10*). On the other hand, in most rural areas of Ecuador, Peru, and Bolivia, complementary agricultural investment is essential to justify such road projects. In these countries, much of the rural areas is already farmed by traditional agricultural methods.

In a study carried out in 1985 and 1986 in nine provinces in Ecuador (Chimborazo, Pastaza, Esmeraldas, Cotopaxi, Tungurahua, Canar, Bolivar, Pichincha, and Loja), it was concluded that between 0 and 15 percent of the potential agricultural areas are not yet used with an average of 7.2 percent (*3*). In other words, 92.8 percent of the potential agricultural area was already used by traditional agricultural methods. The construction of all-weather roads will usually speed up the use of this additional 7.2 percent, which will obviously increase agricultural production by approximately 7 percent.

This increase in production may be insufficient to justify road construction, so additional agricultural benefits are needed. These benefits can be achieved if the traditional agricultural production methods are upgraded to semitechnical or technical production methods. These advanced methods can be introduced only if all-weather accessibility exists (*2,3*). It was concluded from this study that both road construction and agricultural development (a complementary investment) are necessary to economically justify rural investment.

TABLE 2 ECONOMIC CONSTRUCTION COSTS OF RURAL ROADS IN ECUADOR, 1985–1986 (× $1,000/km)

Terrain/Road Type	1	2	3	4	4E	5	5E	6	7
Level	1.1	42	47	50	56	59	69	77	95
Hilly	1.1	57	65	65	71	77	87	99	130
Mountainous	1.1	96	112	105	111	123	140	171	185

TABLE 3 ECONOMIC CONSTRUCTION COSTS OF RURAL ROAD BRIDGES IN ECUADOR, 1985–1986 (× $1,000/km)

	Cost (x $1,000/lineal meter) 1985-1986		
	Span (Meters)		
Type of Cost	≤30	31-60	761
Deck Only	0.6	0.9	1.2
Entire Bridge	1.4	2.0	2.6

TABLE 4 ECONOMIC COSTS OF MAINTENANCE AND RECONSTRUCTION OF RURAL ROADS IN ECUADOR (1985–1986)

Road Type	Maintenance Cost (x $1,000/year/km) by Terrain: Level	Hilly	Mountainous	Reconstruction Costs (x $1,000/operation/km)	Average Period of Reconstruction (Years)
1	0.90	0.95	1.00	1.0	0.5
2	1.00	1.10	1.15	1.1	2
3	1.60	1.65	1.70	2.0	3
4	2.00	2.20	2.50	4.5	7
4E	1.00	1.05	1.10	-	-
5	2.30	2.40	2.60	6.0	7
5E	1.50	1.55	1.60	-	-
6	3.50	3.80	4.10	6.0	7
7	4.50	5.00	5.50	15.0	10

DEFINITION OF AGRICULTURAL BENEFITS ACHIEVED THROUGH ROAD CONSTRUCTION

The economic impact of road construction in agricultural areas was previously analyzed by means of the producer-surplus approach (*10*), which related a large portion of the agricultural benefits to the increase in the area under cultivation as a result of the introduction of new roads. It was concluded that this approach may be insufficient to economically justify rural road construction (*2,3*). In such cases other sources of rural benefits were also explored (*2,3*). These benefits are defined as economic value added. Five sources of economic benefits were identified for the purpose of economic analysis and justification of road construction:

- Improvement in the agricultural exploitation system;
- Savings in transportation costs;
- Cultivation of new agricultural areas;
- Elimination of losses in existing crops caused by lack of access; and
- Elimination of losses to existing crops because of damages when transported over roads with rough surfaces.

An analysis of each of these five economic benefits is presented in the following sections.

IMPROVEMENT IN THE AGRICULTURAL EXPLOITATION SYSTEM (AD_{ex})

Three major exploitation 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. Production rates are low and a large portion of the harvest serves for local subsistence. A total of approximately 72 percent of the cultivated areas in the seven provinces studied was identified as traditional (*2,3*). The semitechnical system is characterized by the use of machinery for land preparation, application of fertilizers in selective form, and the use of improved seed. The farmer uses limited technical assistance and credits extensively. Yields are varied and the harvest is frequently mechanized. Approximately 27 percent of the area studied was identified as semitechnical or partially mechanized in 1985. 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 credits; yields are high and the harvest is frequently mechanized. Approximately 1 percent of the studied area was identified as technical in 1985.

Based on a detailed analysis it was concluded that the main constraints to improving 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. In order to estimate the value added by changing the exploitation system, a production function was developed (*2,3*) for about 60 main agricultural products (e.g., coffee, cacao, banana, citrus fruit, potatoes, garlic, onions, tomatoes, and so on) in the area studied. For each product a production function relating production cost, yields, and exploitation system was developed.

A typical characteristic of the production function is shown in Figure 1, which describes the relationship between the yields and production costs in the traditional, semitechnical, and technical exploitation methods. Under the traditional method, production cost per ha is defined in Figure 1 as C_0, C_1, and C_2, and yields per ha are defined as R_0, R_1, and R_2 for traditional, semitechnical, and technical exploitation systems, respectively. The C and R values were determined for all 60 products and the three levels of exploitation. Representative yield/cost values are given in Table 5. For example, the production cost of cacao is C_0 = \$87/ha and yield is R_0 = 5 qq/ha. One ha equals 10,000 m^2 and one qq equals 100 lb. For the same product—cacao—the production cost and yield in the semitechnical method is C_1 = \$139/ha and R_1 = 9 qq/ha. The unit price (UP) was \$21/qq in 1985. In this case the value added for production of cacao in the traditional exploitation method is defined as

$$AD_0 = (UP = \$21/\text{qq})\ (R_0 = 5\ \text{qq/ha}) - (C_0 = \$87/\text{ha}) = \$18/\text{ha} \quad (1)$$

where

AD_0 = economic value added in dollars per ha in the traditional method and
UP = unit price of the product (in this case cacao).

By investing and improving the production system from the traditional to the semitechnical exploitation method, the value added (AD) is increased from \$18 to \$50/ha (Table 5). The new value added is calculated as follows:

$$AD_1 = (UP = 21)\ (R_1 = 9) - (C_1 = 139) = \$50/\text{ha} \quad (2)$$

where AD_1, C_1, and R_1 are the value added production cost and yield of cacao in the semitechnical method. Because the change in production costs of cacao from the traditional to the semitechnical exploitation system is $C_1 - C_0 = 139 - 87$ = \$52/ha (Table 5), one may conclude that the annual benefits of this investment are $[(AD_1) - (AD_0)]/[(C_1 - C_0)] = (50 - 18)/52 = 0.62$, or 62 percent of annual profit. In the case of coffee the marginal value added is $AD_1 - AD_0 = 49 - 10$ = \$39/ha. The annual profit is $(AD_1 - AD_0)/(C_1 - C_0) = 39/(151 - 110) = 0.95$, or an annual profit of 95 percent.

These two examples appear to indicate that a high rate of return can be achieved by improving the agricultural production method. This economic return has a significant value when compared to the investment in road construction. For example, say that new road construction will provide all-weather accessibility to 500 ha/km. Say that the influence area is cultivated with 40 percent cacao and 60 percent coffee. The value added by improving the traditional farming method to a semitechnical one can be determined according to Equations 1 and 2 and Table 5, namely, for cacao $[(AD_1 = 50) - (AD_0 = 18)]$ (500 ha) (0.4) = \$6,400/year/km and for coffee $[(AD_1 = 49) - (AD_0 = 10)]\ 500 \times (0.6)$ = \$11,700/year/km. Total annual benefit or value added per km is 6,400 + 11,700 = \$18,100/year/km. This high annual benefit can usually be achieved during an approximately 5- to 10-year transition period in which the traditional agricultural production system is transferred into the semitechnical method.

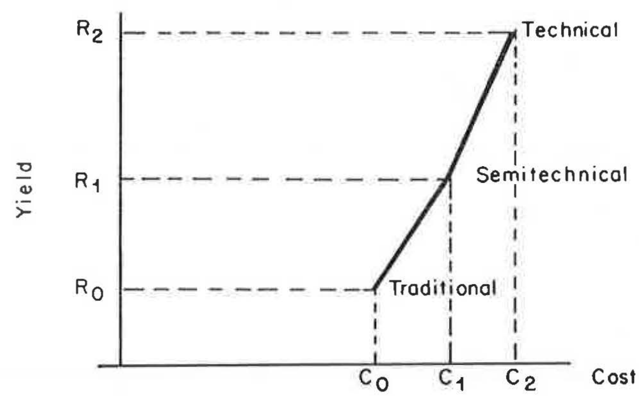

FIGURE 1 Typical characteristic of production function.

REDUCTION IN TRANSPORTATION COSTS (AD_{tr})

Savings on transportation costs in rural South America are usually obtained in two ways: by reducing (a) the VOC by using roads with better surface conditions (*1,3,8,9*), and (b) the cost of transporting agricultural products by using motorized vehicles on new roads instead of animals in areas where roads do not now exist (*2,3*). A rural fleet in such countries as Ecuador and Bolivia would typically consist of 80 percent pickups, 15 percent buses, and 5 percent medium-size trucks. The representative VOC per kilometer for these vehicles in optimum road conditions is \$0.20, \$0.35, and \$0.40/km,

TABLE 5 ANNUAL COSTS, YIELDS, PRODUCTION METHODS, AND VALUE ADDED OF REPRESENTATIVE AGRICULTURAL PRODUCTS (CHIMBORAZO, ECUADOR, 1985)

Name of Product	Traditional Cost* (CO) (\$/ha)	Traditional Yield (RO) (qq/ha)	Semitechnical Cost (C1) (\$/ha)	Semitechnical Yield (R1) (qq/ha)	Technical Cost (C2) (\$/ha)	Technical Yield (R2) (qq/ha)	Unit Price (\$/qq)	Value Added (US \$/ha) Traditional (ADO)	Value Added (US \$/ha) Semitech. (AD1)	Value Added (US \$/ha) Technical (AD2)
Cacao	87	5	139	9	+	+	21	18	50	+
Coffee	110	6	151	10	+	+	20	10	49	+
Bananas	315	269	672	581	+	+	1.7	134	315	+
Citrus Fruits	481	137	875	272	+	+	9	752	1,573	+
Potatoes	608	160	903	240	1,003	360	7	512	777	1,517
Garlic	1,543	64	2,055	120	3,576	244	50	1,657	3,945	7,624
Onions	1,312	120	1,931	200	3,686	352	21	1,208	2,269	3,706
Tomatoes	+	+	1,200	320	2,027	570	14	+	3,280	5,953

*1 quintal (qq) equals 100 lb.
+Technical agricultural technology was not yet used for this product.
(1 ha - 1 hectare)

respectively. The representative VOC per kilometer of this rural fleet is therefore 0.80 • 0.20 + 0.15 • 0.35 + 0.40 • 0.05 = \$0.23/km of rural road (in optimum conditions). The representative VOC in normal (not optimum) and in very poor road conditions is \$0.30 and \$0.46/km, respectively (*2,3*). In other words, very poor accessibility is considered to be road surface conditions that result in an increase of 100 percent in the VOC as compared to the VOC under optimum conditions. A VOC higher than \$0.46/km indicates that the road is practically not accessible.

The transportation of agricultural production in South American rural areas is usually done by pickup or light trucks that carry up to 40 qq, which is equal to 4,000 lb per vehicle. The transportation cost (TC_v) in normal road conditions is therefore $TC_v = (VOC) = \$0.3/\text{km})/40 \text{ qq} = \$0.75 \times 10^{-2}$ qq/km. This vehicle transportation unit cost is only one-fifth to one-sixth of the cost of animal transport by mules. This unit cost relationship is given in Equation 3:

$$TC_a = (5 - 6) \qquad TC_v = 0.037 - 0.045 \tag{3}$$

where

TC_a = transportation cost (\$/qq/km per animal in 1985) and
TC_v = transportation cost (\$/qq/km per vehicle in 1985).

The benefit or value added of transportation (AD_{tr}) equals the savings in VOC by (a) using better road surfaces, and (b) reducing the cost of transporting goods by vehicle instead of by animal.

The transportation value added is defined in Equation 4:

$$AD_{tr} = [(VOC_b - VOC_a)\, ADT \cdot M_a \cdot 30 + \sum (TC_a - TC_v)_j\, (R_j \cdot A_j \cdot N_j)]\, L \tag{4}$$

where

- AD_{tr} = annual value added related to savings in transportation costs,
- VOC_b and VOC_a = VOC (per kilometers) before and after road construction,
- ADT = average daily traffic,
- M_a = number of months with accessibility,
- L = length of road,
- TC_a and TC_v = transportation cost of unit product (qq per km) of animal and vehicle, respectively,
- R_j = agricultural production (per ha per product j),
- A_j = influence area of road (ha) cultivated with product j, and
- N_j = percentage or portion of product transfered by animals.

The following example explains how to determine the transportation value added: $L = 10$ km of rural road provides limited accessibility to 20,000 ha cultivated with 60 percent cacao and 40 percent coffee ($j = 2$). The production rates of cacao and coffee are $R_1 = 5$ and $R_2 = 6$ qq/ha (Table 5). The existing road can provide accessibility during $M_a = 6$ in the dry season only. During this time of year, the $ADT = 20$ vehicles per day. The VOC per kilometer before and after road construction is \$0.16/km. During the dry season 67 percent of the agricultural product is transferred mainly by pickups. The other 33 percent ($N_j = 1/3$) is transferred by animals during the rainy season. The transportation cost difference of unit product, $TC_a - TC_v = \$0.34$/qq/km. Equation 4 shows the value added by transportation AD_{tr} resulting from the construction of this road to a level that can provide all-weather accessibility. According to Equation 4 the annual benefits per km resulting from savings in transportation costs equal \$1,800/km.

It is worthwhile mentioning that in such rural tropical areas as the Amazonas zone in Ecuador, the Selva of Peru, and the eastern zone in the provinces of Beni and Santa Cruz in Bolivia, the use of combined land and river transportation is common. Using river transportation instead of new roads results in a significant reduction in construction costs to only about 5 to 10 percent. This small investment is needed for constructing docks, parking lots, facilities for loading and unloading, and the like. On the other hand, user transportation costs for river transportation are significantly higher (*2,3*).

The following analysis can explain this conclusion. A representative boat used in Ecuador for river transportation has a 40-hp engine and can carry 15 qq or 15 persons. The transportation cost of such a boat was \$0.65/km in 1985 and 1986, which is two to three times more than the VOC on a rural road, mainly because the degree of friction between the water and the boat significantly increases the energy needed per unit weight and unit distance as compared to the energy needs of a motor vehicle that uses a typical rural road in normal conditions. In addition, the average motor vehicle used in rural areas can carry twice the load of a boat. Therefore, the unit cost of transporting 1 qq by boat is $TC_{bo} = [(0.65/\text{km})/15]$ (qq per boat) $= \$4.3 \times 10^{-2}$/qq/km. The annual value added using river transportation AD_{riv} is the present value of the savings in construction, maintenance, and reconstruction costs of a new road as compared to the increase in user costs resulting from using river transportation over land transportation. AD_{riv} is defined in Equation 5:

$$AD_{riv} = 0.9 \cdot (CC) + \sum_{1}^{17} (MC + RC) + \sum_{1}^{17} [TC_v\, (ADT_1 + ADT_2) - TC_{bo}\, (ADT_1 + 2ADT_2)] \cdot 365 \tag{5}$$

where

- ADT_1 = number of passenger vehicles carrying up to 15 persons per vehicle and is approximately equal to number of boats and
- ADT_2 = number of vehicles used to transport agricultural products that carry 40 qq and are equal to twice the number of boats.

(Note: $ADT_1 + ADT_2 = ADT$ is the total average daily traffic.) CC, MC, and RC denote the construction, maintenance, and reconstruction costs, respectively. The construction is usually done in the first year and the maintenance and reconstruction expenditures take place during the economic service lifetime of the road, which is approximately 17 years (*2,3*). TC_v and TC_{bo} denote the transportation costs for a vehicle and for a boat, \$0.23/km and \$0.65/km, respectively. If AD_{riv} is greater than zero, it is feasible to use a river as part of the rural transportation system. For example, say that the construction cost of road Type 4 is \$50,000/km (Table 2). The average annual maintenance cost is \$2,000/km and the average annual reconstruction cost is 4,500/7 = \$700/km (Table 4). The average ADT is 80 vehicles per day ($ADT_1 = 50$ and $ADT_2 = 30$).

Is it feasible to use a portion of 15 km of the river Napo in the Ecuadoran Amazonas zone instead of constructing a new gravel road parallel to the river? According to Equation 5, the value added of river transportation AD_{riv} equals $AD_{riv} = 0.9 \cdot 50{,}000 + (2{,}000 + 700)17 + 17\,[(TC_v = 0.23)\,(ADT = 80) - TC_{bo} = 0.65)\,(50 + 60)]\,365 < 0$. Conclusion: because AD_{riv} is less than zero, it will be more feasible to build a new road instead of using the river to transport goods and passengers. On the other hand, if the ADT is equal to or less than 20 vehicles per day and includes mainly passenger cars ($ADT_1 = 20$ and $ADT_2 = 0$), AD_{riv} calculated according to Equation 5 achieves a positive value, which indicates that it is not feasible to construct a new road at this stage and that it will be more economical to use the river as a link in the rural transportation network until the traffic volume increases to a level that will result in a negative value of AD_{riv} according to Equation 5.

INCREASE IN AREA UNDER CULTIVATION (AD_1)

The value added from the increase in area under cultivation is relatively small (between 0 and 15 percent) in such countries as Ecuador; therefore, the maximum new cultivated area can be 15 percent of the influence area of the road, which is 0.15 • 500 ha/km or 75 ha/km of road. For example, in the case of a cacao plantation (Table 5), $AD_1 = 75$ ha $[(UP = 21)\,(R_0 = 5) - (C_0 = 87)] = \$1{,}350$/km of road length.

ELIMINATION OF LOSSES IN EXISTING CROPS CAUSED BY LACK OF ACCESS (AD_{ac}) AND POOR SURFACE CONDITIONS (AD_{sc})

Accessibility (AD_{ac})

The accessibility value added includes the benefits of eliminating the lack of accessibility to market and of having a better agricultural product as a result of improved road surface conditions (*1*). When a road in an agricultural area is inaccessible (e.g., during the rainy season), the following losses, damages, or disturbances occur: (a) transferring crops to the local market is impossible, and (b) seeding is inefficient.

Surface Conditions (AD_{sc})

Some agricultural products, such as tomatoes, avocados, bananas, strawberries, custard apples, papayas, and plantains suffer significant damage transported over roads with poor surfaces. This type of damage (or quality loss) was analyzed in Ecuador (*1–3*). More explanation of AD_{ac} and AD_{sc} is given elsewhere (*1*) and is not repeated here.

SOCIOECONOMIC ANALYSIS

Economic Analysis

The economic analysis includes the calculations of (a) the road construction costs, and (b) the transportation and agricultural costs and benefits during the lifetime of the road and the determination of such economic indicators as the net present value (NPV), first year rate of return (FYRR), optimum schedule of construction, and internal rate of return (IRR). The net benefit stream is defined as follows:

$$B_t = AD_{ex} + AD_{tr} + AD_1 + AD_{ac} + AD_{sc} - [CC + MC + RC] \qquad (6)$$

where

B_t = net benefit in year t,
AD_{ex} = value added resulting from improvement in the agricultural exploitation system in year t (defined in Equations 1 or 2),
AD_{tr} = value added resulting from reducing transportation costs in year t (Equation 4),
AD_1 = value added caused by an increase in the cultivated area in year t,
AD_{ac} = value added caused by improved accessibility to markets in year t,
AD_{sc} = value added caused by improved surface conditions in year t,
CC = construction cost at the year of construction,
MC = annual maintenance cost at year t in the case of a new road and difference in annual maintenace expenditures after and before improvement of an existing road, respectively, and
RC = annual expenditures for pavement reconstruction in the case of a new road and the difference in annual expenditures for pavement reconstruction after and before road improvement, respectively, in the case of an existing road.

The stream of economic benefits was calculated for 17 years and a sample of the results is given in Table 6, which presents the value of cost and four economic indicators for four representative rural roads in the Ecuadoran province of Chimborazo. For example, a new road (Number 97-0) was constructed to carry low-volume traffic (i.e., 15 vehicles per day). It is a gravel road (Type 4), 4.0 m wide and 5.4 km long. The estimated construction cost of the entire project was \$200,000 (1985). The total value of benefits achieved during 1986 was \$39,000, which includes \$13,000 and \$26,000 for transportation and agricultural benefits, respectively. The net present value at a discount rate of 12 percent is \$543, the first year rate of return is 14.4 percent, the optimum year of construction is 1 (1985), and the IRR calculated for an economic lifetime of 17 years was 36.4 percent.

Social Consideration

South American governments and international finance agencies, such as the World Bank and the Inter-American Devel-

TABLE 6 SOCIOECONOMIC ORDER OF PRIORITY FOR RURAL ROAD CONSTRUCTION (CHIMBORAZO, ECUADOR, 1985; × $1,000)

Road No.	Length (km)	ADT	Road Type Existing	Road Type New	Const. Cost in 1985 (x $1,000)	Benefits in 1986 (x $1,000) Total	Benefits in 1986 (x $1,000) Trans- portation	Benefits in 1986 (x $1,000) Agri- cultural	NPV (12%)	FYRR (%)	Opt. Year of Con- struction	IRR (%)	Socio- economic Priority Index (SEPI)
2124-0	4.5	323	3	7	329	515	508	7	3,950	65.0	1	78.1	65.5
97-0	5.4	15	-	4	200	39	13	26	543	14.4	1	36.4	27.7
3184-0	11.4	5	-	4	940	76	18	58	799	6.0	4	21.4	19.3
2501-0	2.4	161	4E	5	124	16	6	10	303	10.4	2	33.3	16.1
2317-0	3.7	90	2	4	249	33	22	11	135	8.1	2	17.7	15.3

opment Bank, specify that the results of the economic evaluation must be analyzed together with social factors. Because the period of rural road planning is limited to approximately 1 year and always has budget limitations, maximum use is given to analyzing existing published data rather than carrying out new field surveys. The only readily available social data in Ecuador, Dominican Republic, or Bolivia are population density and rate of illiteracy. It is obvious that the higher the population density, the greater the need for transportation to local markets, public institutions, health and educational facilities, and commercial centers. That is to say, for any given investment, the social benefits to be achieved by rural road construction will be greater for a higher population density. The population index (PI) defined in Equation 7 represents this social factor. In other words the higher the PI, the larger the population that is benefited from a given construction dollar value.

$$\text{PI} = \text{population in the road's influence area} \div \text{construction cost} \times C \qquad (7)$$

where C denotes a constant equal to $5,000. Another social index (*1–3*) is the education index (EI) defined in Equation 8:

$$\text{EI} = (\text{RI})\,(\text{PI}) \qquad (8)$$

where RI, as a percentage, is the rate of illiteracy in the population of the influence areas of rural roads. This percentage was determined for the influence area of each rural road. In order to analyze the economic index together with the social indexes the following empirical socioeconomic priority index (SEPI) was derived (*1*):

$$\text{SEPI} = 0.700(\text{IRR}) + 0.225(\text{PI}) + 0.075(\text{EI}) \qquad (9)$$

As is shown in Equation 9, SEPI is composed of economic considerations (70 percent) and social considerations (30 percent). The relationship between the economic and social indicators can of course be modified according to national or local priorities. For example, the population included in the influence area of road Number 97-0 is 370 persons. IRR = 36.4. According to Equation 7 the population index is PI = 370/(200,000) × 5,000 = 9.25, and the rate of illiteracy is 20 percent or RI = 0.2. The SEPI, as is shown in Equation 9, is SEPI = 0.7 (36.4) + 0.225 (PI = 9.25) + 0.075 (RI = 0.2) · (PI = 9.25) = 27.7. The SEPI values calculated using Equation 9 are shown in Table 6. This socioeconomic indicator was implemented (*1–3*) to determine the priorities of constructing and upgrading 1,600 km of rural roads in seven Ecuadoran provinces (*3*): Chimborazo, Pastaza, Pichincha, Cotopaxi, Esmeraldas, Tungurahua, Canar, and Bolivar. A total budget of approximately $95 million was assigned for this purpose. Of this amount, approximately 58 percent was in local currency and 42 percent in foreign exchange.

SUMMARY AND CONCLUSIONS

- In some rural areas in South America, road construction can be economically justified only if other complementary investments are made in agriculture. These complementary investments allow for upgrading the subsistence farming system to a semitechnical or technical one. The basic goal in improving the agricultural exploitation system is to achieve all-weather accessibility for modern agricultural equipment, technical assistance, and adequate communication with the national and international market.
- Nine types of roads are mostly found in the South American rural areas. Three road types can be used during the dry season only and six types are all-weather roads. The width of the all-weather roads varies between 4.0 and 7.2 m. The pavement is composed of a local gravel (or special stone in mountainous areas) base with or without blacktop. The stone pavement needs almost no maintenance during the first 20 to 30 years of service, whereas other types of all-weather pavements with or without blacktop need rejuvenation or overlay every 7 to 10 years in addition to adequate maintenance.
- The planning for road construction is carried out in two stages. In the first, the most economical type of road is determined for the projected volume of traffic. In other words, once the projected traffic volume is known, the type of road requiring minimum transportation expenditures during its service life can be determined. In the second stage, the investment to improve agricultural benefits is determined. The following benefits are obtained from a combined investment in both road construction and agricultural development: (a) an increase in agricultural production through improvement in the agricultural exploitation system, (b) a reduction in users' costs, (c) an increase in the area under cultivation, (d) the elimination of losses in existing crops caused by lack of access, and (e) the elimination of losses in existing crops because of damages incurred when transported over roads with rough surfaces.

- When traffic volume is less than 200 vehicles per day, paved roads are not feasible and gravel or stone roads are constructed to provide all-weather accessibility.
- The economic analysis includes the calculation of (a) the road construction cost, and (b) the transportation and agricultural costs and benefits. This calculation is done for the lifetime of the road and concludes with the determination of such economic indicators as NPV, FYRR, optimum schedule of construction, and IRR. Table 6 gives an example of the results of the economic analysis.
- The conclusions of the economic evaluation are analyzed together with social factors published by the local authorities. The only readily available social data in countries such as Ecuador or Bolivia are the population density and rate of illiteracy. It is obvious that the higher the population density, the greater the need for transportation to local markets, public institutions, health and educational facilities, and commercial centers. Obviously, for any given investment, the social benefits resulting from rural road construction will be greater for a higher population density and higher rate of illiteracy.

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