Simplified Procedures to Manage the Maintenance of Low-Volume Roads

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The maintenance requirements and work activities are considered for three types of low-volume roads: stone, natural gravel, and mechanically stabilized base course pavement (no blacktop). These road types provide about 90 percent of the transport accessibility in rural Ecuador. A description is provided of the activities that were performed during routine, periodic, and emergency maintenance operations. The required level of work for each activity is analyzed for each road type. The calculated work volume and known productivity of labor and equipment are used to determine the annual maintenance needs in terms of workdays of skilled and unskilled labor, and equipment type and quantity. In the next stage of analysis, a computerized unit price analysis is performed in conjunction with the annual maintenance budget. Once the cost analyses and annual maintenance budget are completed, the work schedule and financial distribution are planned. At this stage, a monthly or bimonthly detailed assignment for equipment and labor is performed to meet the maintenance needs for each activity; environmental constraints are also taken into account. The low-cost maintenance procedure and engineering properties of the materials used are described in detail.

Road maintenance plays an important role in minimizing transportation costs, increasing economic productivity, and improving the standard of living in the rural areas of Ecuador (*1*). Adequate maintenance is vital to maintain all-weather accessibility and minimize traffic hazards on unpaved low-volume roads. About 90 percent of the Ecuadoran low-volume rural roads that provide all-weather accessibility fall into the following three categories:

- Natural gravel roads are 4.0 to 6.0 m (13 to 20 ft) wide (see Figures 1 and 2, respectively). These roads are classified as Road Types 4 and 5, respectively (*1, 2*).
- Stone roads (empedrado in Spanish) are classified as Road Types 4E and 5E, and are 4.0 to 5.0 m (13 to 17 ft) wide, respectively. A typical stone road is shown in Figure 3.
- Mechanically stabilized base course pavements (no blacktop) are 6.0 m (20 ft) wide with 0.6 m (24 in) of shoulder on each side (see Figure 4). This road is classified as Road Type 6.

Natural gravel and stone roads are used for traffic levels of up to 100 vehicles per day (vpd) for the narrower road widths, and up to 150 vpd for wider road widths. The stabilized base course pavement is used for traffic volumes of 150 to 250 vpd. Experience with the performance and maintenance of these low-volume roads indicates that the most frequent causes of surface distress are as follows:

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FIGURE 1 Typical 4.0 meters of gravel road.


FIGURE 2 Typical 6.0 meters of gravel road.


FIGURE 3 Mechanically stabilized base course pavement.

FIGURE 4 Typical stone road.

- Dust formation, which is caused by traffic (wheel repetition), occurs mainly on the gravel roads and to a lesser extent on the base course roads.
- Raveling or disaggregation of the surface and loosening of the coarse aggregates occurs mainly on the gravel roads, less frequently on the base course roads, and least frequently on the stone roads.
- Rutting or plastic deformation occurs in all types of low-volume road surfaces, but with the greatest severity on gravel roads.
- Road surface erosion and potholes occur mainly in natural gravel roads, especially when the longitudinal slope is over 4 percent. Base course roads begin to deteriorate significantly when the longitudinal slope is over 7 percent. Stone roads rarely show erosion distress.
- Corrugation is typical in uncrushed gravel roads and is less common on base course roads.
- Roughness and upheaval distress occur in all road types because of subgrade movement or pavement instability.

Maintenance activities are defined as the specific work operations that are performed to minimize road distress or deterioration, and provide an adequate level of accessibility to the rural roads. The organization of the work into discrete activities enables the simplification and optimization of planning and the minimization of expenditures. The annual maintenance work is defined as the sum of the volume of work performed in all activities for the entire year. The annual volume of work for each activity is derived from the evaluation of road inventory data and the desired level of road service. Once the work needs and daily production for each activity are known, the annual and monthly requirements for equipment, labor, and materials can be determined.

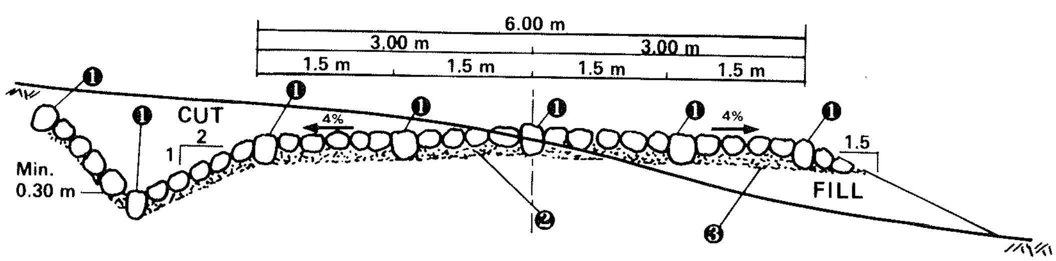
The work programming is the final task of the maintenance planning stage. All maintenance activities are monitored and recorded to achieve the following objectives: (a) identify actual maintenance work done, (b) update equipment and labor production, (c) update and adjust road maintenance norms based on the road's performance record, and (d) update and adjust the equipment, labor, and maintenance needs for the rural road network.

ENGINEERING PROPERTIES OF RURAL ROADS

The all-weather rural roads in Ecuador are designed to provide safe traveling speeds of 25, 40, and 50 km/hr (15.25 to 32 mph) for mountainous, hilly, and level terrains, respectively (*1*). The design California bearing ratio (CBR) of the pavement material is 20 for Road Types 4 and 5, and 60 for Road Type 6. Pavements were designed according to the methods described in other studies (*3-5*).

The granular pavement thickness usually varies between 12 and 40 cm (5 and 16 in), depending on subgrade CBR, traffic loading, and environmental conditions. The maximum aggregate size is 5 to 7.5 cm (2 to 3 in) for Road Types 6 and 4 or 5, respectively. Pavement failure is defined as a rut depth of 7 to 10 cm (3 to 4 in) on top of the subgrade (*1, 4, 5*).

The stone road (or camino empedrado in Spanish) is constructed of two aggregate sizes: 10 to 15 cm (4 to 6 in) and 20 to 25 cm (8 to 10 in). The larger stone is defined as master stone and is used as an anchor, as shown in the typical cross-section depicted in Figure 5. The master stone is spaced at a distance of 1.0 to 1.5 m (3 to 5 ft) in the cross-section. It is used to develop the side pressure that increases the friction between the stones in the pavement, which in turn increases its bearing capacity.



❶ MASTER STONE

❷ SANDY LAYER (THICHNESS 5 cm)

❸ COMPACTED SUBGRADE

FIGURE 5 Typical cross-section of stone road.

The smaller rock (10 to 15 cm) is properly shaped and is located by skilled labor in between the master stone on top of a thin layer of nonplastic sandy material. The thickness of the sandy material is about 5 cm (2 in). New stone roads hardly require any pavement maintenance during the first 20 to 30 years. In other words, new stone roads give adequate accessibility with minimum maintenance costs during their entire economic lifetime, which is 17 years in Ecuador (*1, 6*).

MAINTENANCE ACTIVITIES

Each maintenance activity is performed to improve or eliminate a certain distress in each road element. For example, gravel and stone patching is performed to reduce surface erosion and potholes. Cleaning culverts and ditches, and controlling vegetation reduces surface rutting or plastic deformation. Regraveling or surface grading reduces raveling, surface disaggregation, and roughness. The definitions of the work activities needed to maintain Ecuadoran rural roads are given in Table 1 (*2*).

The activities defined in Table 1 are classified into three categories: routine (R), periodic (P), and emergency (E). These activities cover all maintenance work needed to maintain the pavement, drainage facilities, rights-of-way, bridges and water crossings, slopes, signs, and safety elements. Each maintenance activity in Table 1 is assigned a unique code. The average rate of daily production of each activity is also given. The variation of the daily production is attributed to the difference in climatic or topographical conditions and to the availability of local labor and materials.

The Ecuadoran climate plays an important role in the productivity of maintenance work. Three climatic zones can be distinguished: tropical, subtropical, and arid. The Ecuadoran tropical zones are located both in the Amazonas region east of the Andes Mountains and in a low-altitude narrow strip to the west of the Andes. The annual precipitation in these tropical zones is 2500 to 5000 mm/yr (100 to 200 in). The subtropical zone covers most of the Pacific Coast and the mountainous region, with an annual rainfall of approximately 600 to 2500 mm/yr (24 to 100 in). The arid zones have a precipitation of less than 600 mm/yr (24 in) and are located in the southern mountains and in some regions along the Pacific Ocean (Manabi).

The daily production for each activity shown in Table 1 was determined in 1985. For example, the daily production of gravel pothole patching varies mainly between 8 and 15 m^3/day. The lower value represents the average productivity in the higher altitudes, such as in the province of Chimborazo, and the higher value of production can be achieved in the lower altitudes or in the arid zone. Once the daily production for each maintenance activity is known, the daily requirements of labor, equipment, and materials can be determined by means of a maintenance work method statement (see Table 2).

A typical work statement is shown in this table for maintenance activity 111 R, gravel pothole patching. The work statements for all other activities can be found elsewhere (*2*). The maintenance statements are periodically updated to reflect current changes and adjust production rates.

It can be seen in the specific example of Table 2 that to produce 8 m^3 of gravel patching of graded aggregates, it is

TABLE 1 MAINTENANCE ACTIVITIES AND DAILY PRODUCTION

Code	Activity	Daily Production
111 R	Gravel pothole patching	8*-15 m³
112 R	Stone (empedrado) pothole patching	2*-3 m³
121 R	Cleaning of culverts	6-8* units
122 R	Ditch cleaning (labor)	1-3* ditch-km
131 R	Vegetation control (labor only)	0.5-0.6* ha
132 R	Small slide removal	8*-10 m³
133 R	Repair of small fill and edge failure	8*-10 m³
141 R	Cleaning of bridges and low-cost water crossings	2-4* units
211 P	Regraveling or pavement strengthening	250*-300 m³
212 P	Surface grading	3*-4 km
221 P	Ditch cleaning (Motor grader)	3-5* ditch/km
222 P	Replacement of culverts	1-2* units
231 P	Vegetation control (Machine)	1-2* ha
241 P	Bridge and ford maintenance and small repair	2*-3 units
251 P	Road sign servicing	6-8* units
310 P	Preparation of granular or gravel pavement material	100-200* m³
312 P	Preparation of stone pavement material (empedrado)	20-25* m³
313 P	Transportation of pavement materials	500-600* m³
314 P	Supervision and other periodic activity	20*-25 km
333 P	Other periodic maintenance	6*-10 work days
410 E	Machine slide removal	100-150* m³
411 E	Machine fill pavement reconstruction	60-80*-100 m³

R = routine, P = periodic, E = emergency.

* Represents the daily production of the province of Chimborazo.

TABLE 2 MAINTENANCE WORK METHOD STATEMENT

ACTIVITY: Gravel pothole patching — Code No. 111 R

Definition and Purpose: Manual repair of small surface area of gravel pavement with properly graded aggregate material to repair potholes, small depressions and other traffic hazard areas in order to restore a smooth riding surface.

Execution Criterion: Pothole deformation depth of 4 in. or when existing potholes are filled with water, creating traffic hazard.

Unit of Measure: m^3

Labor	Standard Work Method
1 foreman 8 unskilled laborers 1/3 driver	1. Loading and transporting aggregate materials 2. Placing safety devices and signs as required
Equipment 1/3 dump truck, (8-ton) 1 hand compactor 1 set of hand tools (4 shovels, 3 picks, 3 rakes)	3. Drying out excess water from potholes in tropical and subtropical zones 4. Placing select aggregate and smoothing out with rakes 5. Compacting with hand compactors and by moving trucks back and forth over patch
Materials Properly graded aggregate prepared and paid according to activity 310.	6. Leaving patch as smooth as possible 7. Removing safety devices and signs

Average Daily Accomplishment

$8 m^3$

necessary to use one hand compactor, one-third of an 8-ton dump truck, and a complete set of hand tools. The required labor for this activity includes one foreman, eight unskilled laborers, and one-third of a driver. The maintenance work statement also gives the definition and purpose of each activity, the execution criterion, and a short description of the work method.

The required daily labor and equipment needed to achieve the daily production of work for each maintenance activity in the Ecuadoran mountainous province of Chimborazo are given in Tables 3 and 4, respectively. For example, to clean 5 km of ditches (activity 221 P, it is necessary to use one-third of a dump truck, a complete set of hand tools, and one motor grader.

In the case of emergency maintenance activity 410 E, one dump truck, one loader, one tractor, and one set of hand tools need to be operated by two operators, two assistants, one driver, two unskilled laborers, and one foreman to remove 150 m^3 of landslide material. The detailed labor requirement is shown in Table 3. Another example involves maintenance activities 111 R and 112 R, in which one foreman, eight unskilled laborers, and one-third of a driver are needed to produce 8 m^3 and 2 m^3 of gravel or stone pothole patching (see Table 1).

The additional daily requirements for a platform truck, a concrete mixer, water pumps, and mechanical saws are less frequently needed in the maintenance of rural roads.

ROAD AND BRIDGE INVENTORY

The principal objective of the inventory of rural roads and bridges is to provide updated information for the planning of maintenance needs in terms of the volume of work and the requirements for equipment and labor (*1, 2*). In other words, the inventory and road evaluation are used to optimize the maintenance expenditures for each road section in such a way that uniform accessibility will be provided to the users. Only a brief description of the four basic inventory elements is provided, as follows:

- *Identification of each road link*: Location, coding, and determination of the level of accessibility of the local population and agricultural production.
- *Engineering properties*: Length, width, type of road and terrain, number of culverts and bridges, type and length of ditches, and number of traffic signs.
- *Field evaluation*: Number and size of potholes, surface conditions, density and height of vegetation, slope failure hazards, performance of drainage facilities, types of soils, and material haulage distance.
- *Other observations*: Special maintenance needs and suggestions for repair of pavement, drainage facilities, bridges, fords, and other elements included in the right-of-way.

One engineering team can inventory and evaluate approximately 50 km of rural roads a day.

MAINTENANCE WORK PLANNING

Annual maintenance work plans describe which operations should be performed, in quantity and quality, to meet a predetermined user service level. The selected service level will establish costs for both the maintenance effort and the users. In order to keep vehicle operating costs (VOCs) at an absolute minimum, the rural road network would have to be maintained

TABLE 3 DAILY LABOR REQUIREMENTS

Activity	Foreman	Unskilled Laborers	Drivers	Motor Grader Op.	Roller Op.	Op. Assistance	Mason	Mower Op.	Loader Op.	Tractor Op.	Engineer
111 R	1	8	.33								
112 R	1	8	.33								
121 R	1	8	.33								
122 R	1	8	.33								
131 R	1	8	.33								
132 R	1	8	.33								
133 R	1	8	.33								
141 R	1	8	.33								
211 P	1	2	1.33	1	1	2					
212 P	1	2	1.33	1	1	2					
221 P	1	4	.33	1	1	1					
222 P	1	8	.33				1				
231 P	1	4	.33					1			
241 P	1	8	.33								
251 P	1	4	.33								
310 P	1	2	2			2			1	1	
312 P	1	8	.33								
313 P			1								
314 P			1								1
333 P	1	4	.33								
410 E	1	2	1			2			1	1	
411 E	1	2	1			2			1	1	

TABLE 4 PRINCIPAL DAILY MAINTENANCE EQUIPMENT REQUIREMENTS

Activity	Dump Truck (8-ton)	Hand Roller	Hand Tools	2.5-8.0 Ton Vibratory Roller	Water Tanker	Motor Grader	Mower	Loader	Tractor	Screening Plant	Pickup (2.5-ton)
111 R	.33	1	1								
112 R	.33		1								
121 R	.33		1								
122 R	.33		1								
131 R	.33		1								
132 R	.33		1								
133 R	.33	1	1								
141 R	.33		1								
211 P	.33		1	1	1	1					
212 P	.33		1	1	.5	1					
221 P	.33		1			1					
222 P	.33		1								
231 P	.33		1				1				
241 P	.33		1								
251 P	.33		1								
310 P	2							1	1	1	
312 P	.33		1								
313 P	1										
314 P											1
333 P	.33		1								
410 E	1		1					1	1		
411 E	1		1					1	1		

to a nearly as-built condition. This, however, would not be physically possible without first making a very large expenditure to regravel and reconstruct the granular pavement surface. Furthermore, even if this could be accomplished, it is not usually economically prudent to maintain a rural road system at the as-built top-service level. The reason for this is that minimizing user costs would maximize maintenance costs, as shown in Figure 6.

The relationship between user costs and maintenance effort is real and is exponential in nature. An economic trade-off exists between user and maintenance costs. The optimum, at which total costs are at a minimum (see Figure 6), is the desirable level of service. This level of service varies with traffic volume, topography, climatic conditions, and type of road surface. The optimum level of maintenance service for a mountainous rural region is presented in Table 5 (*1, 2, 6*). For example, the maintenance service level of activity 111 R, gravel pothole patching, is 4.0 and 6.0 m^3/km road for Road Types 4 and 5, respectively. This service level was determined as follows (*2*).

In order to achieve the optimum level of maintenance service in Chimborazo, it was found that 1/100 of the road's surface should be patched annually with an average patching depth of

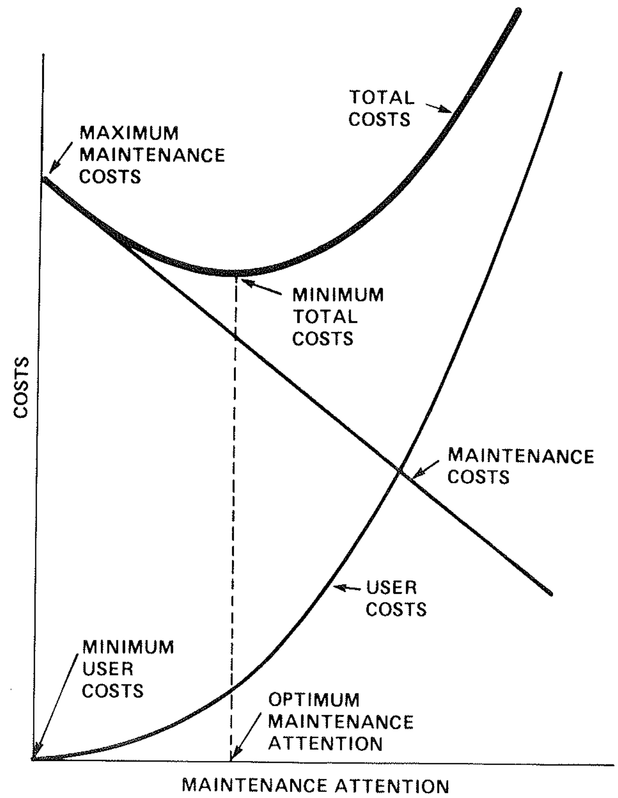


FIGURE 6 Maintenance costs versus user costs.

10 cm. The pavement width of Road Types 4 and 5 is 4.0 and 6.0 m, respectively. Therefore, the service level of gravel patching is 1000 m × 4.0 m × 0.1 m × (1/100) = 4 m^3/km for Road Type 4, and 6 m^3/km for Road Type 5. The optimum level of service was determined in a similar manner for other maintenance activities, and the results are shown in Table 5.

Once the optimum level of service is established and the road inventory is completed, the annual maintenance needs can be calculated for each activity. For example, the annual needs for gravel pothole patching are calculated as follows:

$$GPP_{ijk} = \sum_{i=1}^{i} \sum_{j=1}^{j} \sum_{k=1}^{k} LNG_{ijk} \cdot SL_{ijk} \cdot AF_{ijk}$$

where

GPP = the total annual gravel pothole patching in m^3 of activity 111 R for all road types (i=4, j=5, and k=6);
LNG = the lengths of all road types (i=4, j=5, and k=6);
SL = the service level of gravel patching in m^3/km given in Table 5 for Road Types 4, 5, and 6; and
AF = the adjustment factor of the current road condition, which is determined from the road inventory and evaluation (*2*).

For example, the surface of 3.3 km of Road Type 5 was evaluated in the inventory as being in very poor condition. The engineering interpretation of such surface condition is that the volume of maintenance work should be increased by 20 percent to provide optimum road accessibility (*2*). In other words, the adjustment factor, AF, equals 1.2. According to Table 5, the annual service level (SL) of patching is 6.0 m^3. Therefore, the annual gravel patching needs of activity 111 R for this road are 3.3 km × 6.0 m^3/km × 1.2 = 23.8 m^3/year.

In addition to the work needs that were determined by the overall maintenance plan just described, other maintenance needs result from the following conditions:

- Deficiencies that were encountered during regular field inspection,
- Deficiencies that were noticed by crew foremen while performing another work activity, and
- Requests for maintenance services by users, usually in the form of complaints and emergencies.

TABLE 5 ANNUAL MAINTENANCE LEVEL OF SERVICE

Activity	Unit of Measurement	Level of Service by Road Type				
		4	5	4E	5E	6
111 R	m^3/km of road	4.0	6.0	-	-	6.0
112 R	m^3/km of road	-	-	4.0	6.0	-
121 R	Percentage of all culverts	50%	50%	50%	50%	50%
122 R	Percentage of existing ditches	50%	50%	50%	50%	50%
131 R	ha/km of road	0.1	0.1	0.1	0.1	0.1
132 R	m^3/km of road	2.0	2.0	2.0	2.0	2.0
133 R	m^3 of road	0.5	0.5	0.5	0.5	0.5
141 R	Percentage	100	100	100	100	100
211 P	m^3/km of road	60	90	-	-	90
212 P	Percentage of road surface	100	100	-	-	200
221 P	Percentage	50	50	50	50	50
222 P		20	20	20	20	20
231 P	ha/km of road	10	10	10	10	10
241 P	Percentage	100	100	100	100	100
251 P	Percentage	50	50	50	50	50
310 P	m^3/km of road	64	96	-	-	96
312 P	m^3/km of road	-	-	4.0	6.0	-
313 P	m^3km/km of road	1,600	2,400	100	150	2,400
314 P	km/km of rod	2	2	2	2	2
333 P	Man-days/km of road	0.5	0.5	0.5	0.5	1.0
410 E	m^3/km of road	10	10	10	10	10
411 E	m^3/km of road	2	2	2	2	2

Requests for services by users of unpaved roads should not be treated lightly. As a matter of fact, public awareness of maintenance needs should be encouraged to reduce total efforts and costs. For example, if a foreman reports a buildup of debris at the entrance to a culvert and the debris is cleared before the next storm, road failure and traffic hazards can be avoided. It is recognized that although annual work planning programs define theoretical overall work objectives, short-term schedules must be responsive to actual needs. Therefore, deviations from work programs may be required and should be expected. An example of the annual maintenance needs for 1000 km of rural roads in Chimborazo is given in Table 6. This inventory includes the following road types: (a) 350 and 200 km of gravel Road Types 4 and 5, respectively; (b) 150 km of stone Road Type 4E and 150 km of Road Type 5E; and (c) 150 km of crushed base Road Type 6.

Along the 1000 km of road are 20 bridges and about 330 culverts, or about one culvert every 3 km. There are also 500 km of ditches, two-thirds of which are cleaned by labor; one-third are cleaned by machines. There are also 100 signs along these roads.

The volume of maintenance work for each activity and each road type is shown in Table 6. These work quantities were calculated by multiplying the road's length by the annual maintenance level of service (given in Table 5). For example, as shown in Table 5, the annual level of service is 4.0 and 6.0 m^3/km of activity 111 R for Road Types 4 and 5, respectively. The annual maintenance need is therefore 350 km $\times$ 4 m^3/km = 1400 m^3 and 200 km $\times$ 6 m^3/km = 1200 m^3, respectively (see Table 6). The annual work for all Road Types 6 is 150 km $\times$ 6 m^3/km = 900 m^3. The total annual needs for activity 111 R are 1400 + 1200 + 900 = 3500 m^3. The annual needs for stone patching (activity 112 R) for 300 km of stone roads are 1500 m^3. The annual needs in terms of work volume for each activity and for the total maintenance work shown in Table 6 are used to program the annual requirements for labor and equipment.

Annual Programming for Labor and Equipment

Annual maintenance labor and equipment programming is based on (a) the total annual work volume for each activity, as shown in Table 6, (b) the daily production of each activity, as shown in Table 1, and (c) the requirements for labor and equipment needed to meet this daily production, as shown in Tables 3 and 4, respectively.

For example, the annual work volume of activity 111 R (gravel pothole patching) is 3500 m^3 (Table 6). The daily production is 8 m^3 (Table 1). Therefore, the annual crew day is 3500/8 = 437 crew days. As shown in Table 3, each crew day includes one foreman, eight unskilled laborers, and 0.33 drivers. Therefore, the annual number of workdays for activity 111 R is 437 $\times$ 1 = 437 workdays for the foreman, 437 $\times$ 8 = 3496 workdays for unskilled laborers, and 437 $\times$ 0.33 = 144 workdays for drivers. The sum of all required workdays for all 22 maintenance activities is the annual programming for labor. The total required workdays needed to maintain 1000 km of rural roads in Chimborazo is shown in Table 7.

The annual programming of equipment days (EDs) is performed in a similar manner. The total annual number of EDs needed to perform activity 111 R is 3500/8 = 437 EDs. As shown in Table 4, each ED includes 0.33 dump trucks, one manual compactor, and a complete set of hand tools for eight unskilled laborers. Therefore, the annual number of EDs needed to perform activity 111 R is 437 $\times$ 0.33 = 145 EDs for the dump truck, 437 $\times$ 1 = 437 EDs for the manual roller, and 437 $\times$ 1 = 437 EDs for hand tools.

TABLE 6 RELATIONSHIP BETWEEN ANNUAL MAINTENANCE NEEDS AND ROAD TYPE (1000 KM OF RURAL ROADS)

Activity	Road Length	4	4E	5	5E	6	Total Annual Work Volume	Unit Price (sucres)*	Total Annual Cost (sucres)
		350	150	200	150	150			
111 R	m³	1400	0	1200	0	900	3500	1817	6,359,500
112 R	m³	0	600	0	900	0	1500	6228	9,342,000
121 R	U	525	225	300	225	225	1500	2055	3,082,500
122 R	km	58	25	33	25	26	167	5409	903,303
131 R	ha	35	15	20	5	20	105	20553	2,158,065
132 R	m³	700	300	400	300	300	2000	1713	3,426,000
133 R	m³	175	75	100	75	75	500	2303	1,151,500
141 R	U.	2	3	3	4	8	20	4111	82,220
211 P	m³	21000	0	18000	0	13500	52500	326	17,115,000
212 P	km	350	0	200	0	200	750	23645	17,733,750
221 P	km	30	12	17	12	12	83	7860	652,380
222 P	U	210	90	120	90	90	600	7672	4,603,200
231 P	ha	2.5	2.5	3	3	4	15	7715	115,725
241 P	U	2	3	3	4	8	20	8473	169,460
251 P	U	35	15	20	15	15	100	1515	151,500
310 P	m³	22400	0	19200	0	14400	56000	478	26,768,000
312 P	m³	0	600	0	900	0	1500	685	1,027,500
313 P	m³-km	560000	15000	480000	22500	360000	1437500	16	23,000,000
314 P	km	700	300	400	300	300	2000	310	620,000
333 P	h/day	175	75	100	75	150	575	1650	948,750
410 E	m³	3500	1500	2000	1500	1500	10000	554	5,540,000
411 E	m³	700	300	400	300	300	2000	1351	2,702,000

Total: Sucres 127,652,353
U.S. $ 1,329,712

*U.S. $1 = 96 sucres

TABLE 7 TOTAL REQUIRED ANNUAL WORKDAYS TO MAINTAIN 1000 KM OF RURAL ROADS

Definition of Labor	Foreman	Unskilled Laborers	Drivers	Motor Grader Operator	Roller Operator	Operator Assistants	Mason	Mower Operator	Loader Operator	Tractor Operator	Engineer
Total Annual Work Days	3200	20,000	4000	500	480	1700	300	400	150	400	100

TABLE 8 TOTAL REQUIRED ANNUAL EQUIPMENT DAYS TO MAINTAIN 1000 KM OF RURAL ROADS

Equipment Type	Dump Truck (8-ton)	Hand Roller	Hand Tools	2.5-8.0 Ton Vibratory Roller	Water Tanker	Motor Grader	Mower	Loader	Tractor	Screening Plant	Pickup (2.5-ton)
Total Annual Equipment Days.	4000	500	3000	450	300	500	150	400	400	300	100

TABLE 9 LABOR REQUIRED TO MAINTAIN 1000 KM OF RURAL ROADS

Professional Class	Number of Professionals
Foreman	16
Unskilled labor	100
Drivers	22
Motor grader operator	4
Roller operator	3
Loader operator	3
Tractor operator	3
Mower operator	1
Assistant operator	9
Mason	2
Engineer/supervisor	1

TABLE 10 ANNUAL EQUIPMENT REQUIRED TO MAINTAIN 1000 KM OF RURAL ROADS

Type of Equipment	Amount
Tractor (D7)	1
Tractor (D6)	2
Water tank (2,000 gal)	2
Dump truck	20
Motor grader	4
Vibratory roller	3
Hand roller	3
Loader	3
Mechanical mower	1
Portable water pump	2
Small concrete mixer	1
Screening plant	2
Pick-up truck	1
Communication units	3
Portable generator	1
Platform (25-ton)	1
Maintenance truck	1
Mechanical saw	3
Small water tank (200 gal)	1

Another example in regard to regraveling (activity 211 P) is given in Table 6, in which the total annual volume of work is 52,500 m^3/1000 km of road. The daily production of a crew day (CD) is 250 m^3 (see Table 1), therefore the annual CD or ED is 52,500/250 = 210 CDs or EDs. As shown in Table 3, each ED includes 0.33 dump trucks, one vibrator roller, one water tank, and one motor grader. The annual number of EDs is therefore $0.33 \times 210 = 70$ EDs for the dump truck and 210 EDs each for rollers, water tank, and motor grader. It should be noted that the preparation of material and its transportation to the road is included in other activities, namely 310 and 313, respectively. The total required EDs for the principal maintenance equipment that is needed to maintain 1000 km is given in Table 8.

The quantity of labor and equipment is calculated in the final stage of programming. The annual number of working days in the field should be determined to complete this stage. This number is a function of the maintenance needs, weather conditions, and type of activity. The foremen, drivers, and unskilled laborers are working approximately 200 days/yr in the field and the operators are working on the road about 150 days/yr. Loaders and screening plants are being used 100 days/yr. In addition to the equipment shown in Table 8, a rural road maintenance unit also needs a platform, a maintenance truck (25-ton), communication units, mechanical saws, generators, a concrete mixer, and portable water pumps. The typical labor and equipment that is needed to maintain 1000 km of rural roads is shown in Tables 9 and 10.

Scheduling Procedures

Detailed monthly scheduling enables the field crew to clearly understand its short-term maintenance work objectives. Experience indicates that, without a sound, short-term schedule, crews frequently perform the easiest and most convenient tasks instead of those that are actually required. Experience in Ecuador indicates that work schedules for rural roads should be prepared for monthly periods. The actual preparation should be undertaken as a joint effort between the engineers and foremen who will be responsible for the work. Once the requirements and needs for labor, equipment, and materials have been determined and before the schedules are prepared, consideration must be given to the following:

- Timing (when the work must be performed),
- Location (where the work must be performed),
- Local obstacles (which mainly result from bad weather conditions),
- Duration (how long the work will take), and
- Resources (requirements for equipment, personnel, and materials).

Typical monthly work schedules in Chimborazo indicate that 5 and 10 percent of the annual resources for gravel and stone patching (activities 111 R and 112 R) are performed monthly from January to April and from May to December, respectively. In other words, the expenditure of surface patching can be made better during the relatively dry season from April to December. Another schedule indicates that equal amounts of bridge and ford maintenance work are performed from March to December. No such activity is undertaken in the stormy season during January and February. Culverts can be cleaned properly only in the dry season between June and December.

Preparation of Annual Budgets

The preparation of the annual budget is the last task in the maintenance management procedure. This task is rather simple once the annual and monthly resource needs for equipment, labor, and materials for each work activity are known. A detailed unit price analysis is performed to achieve an accurate cost estimate. A simple, computerized cost analysis that includes the economic costs of equipment, labor, material, haul distance, and rate of production is completed to determine the direct cost for each maintenance activity (*1, 2*). For each direct cost there are other indirect expenditures, such as overhead, contingencies, supervision, and profit if the work is performed by a private contractor. The representative unit cost for each work activity in local currency ($1 (U.S.) = 96 sucres in 1985) is given in Table 6. For example, the unit price of gravel and stone patching activities 111 R and 112 R is 1817 and 6228 sucres/m^3, respectively. The total annual budget needed in 1985 to maintain 1000 km of rural roads was 127,652,353 sucres or $1,329,712, which is about 4 to 5 percent of the road construction cost.

Report Monitoring and Work Control

The maintenance management of rural roads only requires the use of a simple field report that can easily be implemented on the site by the foreman or a senior crew member to report and control work. The purposes of the field report are as follows:

- To identify and control the volume of work for each maintenance activity for each road,
- To update and adjust the rate of production for the different activities and road locations, and
- To update the maintenance needs and requirements for labor, equipment, and materials.

The field report includes accurate and reliable descriptions of (a) work location; (b) work accomplished; (c) personnel, by name, labor classification, and number of hours/week; (d) equipment, by type, identification number, and hours assigned to the activity; (e) materials; and (f) comments on any special problem observed during the actual field operation. This information can easily be stored in a personal computer and has been found to be very useful in increasing production and improving the quality of maintenance work. In addition, the field information is valuable for any statistical analysis regarding the conditions and needs of maintenance equipment.

SUMMARY AND CONCLUSIONS

A simple methodology was presented for planning the maintenance of low-cost gravel, stone, and base course roads without blacktop. The pavement width of these roads varies between 4.0 and 7.2 m (13 to 24 ft) and the roads are designed to carry up to 250 vpd. The different rural roads used in Ecuador are shown in Figures 1 to 4. The engineering classification of these roads is also presented.

The 22 work activities for routine, periodic, and emergency maintenance are shown in Table 1 together with daily work production. The methodology for determining the labor, equipment, and materials required for each maintenance activity is presented and a typical example related to gravel potholes demonstrates the method of calculation (Table 2).

The optimum maintenance level is defined as the work effort needed to minimize the total expenditures of both road users and maintenance costs. The optimum maintenance level of service varies with traffic volume, topography, climatic conditions, and type of road surface. A typical optimum level of maintenance service for the rural Ecuadoran mountainous region is presented in Table 5. When these levels of service were implemented, the rural roads were maintained in good condition and the VOC was approximately $0.3 to $0.5/km. When the level of maintenance was reduced, the VOC increased from $0.5 to approximately $0.8/km. The upper-limit VOC is related to zero maintenance and a surface roughness of over 10 m/km.

The annual maintenance needs for each activity are determined from a simplified road and bridge inventory and evaluation, the criterion of optimum level of maintenance service, deficiencies that were encountered during regular field inspection, deficiencies that were noticed by crew foremen while performing other work activities, and requests for services by users.

Once the total annual maintenance needs are known the requirements for equipment and labor can be determined in terms of equipment days and workdays. A total of 10,000 equipment days and 13,300 workdays are needed to maintain 1000 km of rural roads in the mountainous region of Ecuador. For local conditions, this requires about 16 foremen, 100 laborers, 22 drivers, 23 different equipment operators, and their assistants under the overall supervision of a road maintenance engineer. The following basic heavy equipment is used to maintain these roads: four motor graders, three tractors, twenty dump trucks, two water tankers, six vibratory and hand rollers, three loaders, two screening plants, one maintenance truck, one platform, and other smaller pieces of equipment (Table 10). An optimum cost level of maintenance service is obtained when the annual expenditures are approximately 4 to 5 percent of the initial economic construction costs.

A monthly work schedule is needed to ensure an adequate maintenance operation. This work schedule involves timing and location; local obstacles, which mainly result from water conditions; duration of the operation; and the resources required for equipment, personnel, and materials.

A simple procedure is needed to control the quality and quantity of work, update and adjust the rate of production, and update maintenance needs and requirements for labor, equipment, and materials.

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Road Maintenance Costs and Research Directions of Low-Volume Logging Roads in New Zealand

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Road maintenance costs are a significant consideration in the management of pavements for logging traffic. Cost and volume data have been gathered from a number of logging roads, within a common forest area, over a 15-yr period. Axle loads were usually close to the legal highway limits (8.2 tonnes equivalent single-axle) and volumes ranged from 2,000 to 250,000 tonnes/yr. A regression analysis of the data confirmed that maintenance costs on unsealed gravel pavements increase as the volume of logs carted over the road increases. A sealed road that was constructed to a standard that gives low Benkelman beam deflections showed an expected decrease in maintenance cost; this relationship is quantified. Overall, the data showed a wide range of maintenance costs versus volume hauled, with no strong statistical correlation between the two. The observations presented can be readily upgraded to allow for inflation (using a construction cost index). As more data become available, they can be used as one component in a multivariable model to optimize the design, rehabilitation, or reconstruction of a road, and improve the economics of a log transportation system. Even without this sophisticated modeling, they can provide valuable indicators for roading economies. Research directions within the New Zealand logging industry are detailed with particular emphasis on the means by which the industry can be effectively informed of known techniques in planning, economics, and construction. General comments are made on current and expected research and extension work.

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The New Zealand forest industry is becoming increasingly aware of rising costs as harvesting moves into plantation forests that were established on steep and difficult terrain. "Old crop" forests that were established on easy terrain during the early 1930s as part of the government's depression employment scheme have mostly been harvested. The "new crop" forests that were planted since 1950 are now coming into production. It is becoming apparent that the economic justifications used in the establishment of these forests were excessively optimistic, particularly in the state sector in which soil stabilization and employment opportunities were viewed as additional objectives. The requirement to provide an economic return on investment was not given primary importance.

New Zealand's economic philosophy is undergoing a major change, from a production base that is directly or indirectly subsidized to one that is unsubsidized and market-driven. The emphasis has been diverted from attempts by the government to assist industries or sectors that are seen as desirable, or successful, toward a situation of government neutrality. This change has led to alterations in the tax structure that now give