A PRELIMINARY EVALUATION OF PAVED AND UNPAVED ROAD PERFORMANCE IN BRAZIL

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The study of unpaved and paved road performance was a principal part of the "Research of the Interrelationships of Road Construction, Maintenance and User Costs" conducted in Brazil during the period 1975 to 1979. The paper outlines the experimental design methodology and measurement techniques for the pavement and maintenance studies. Preliminary results of the performance of unpaved and paved roads, monitored on 30 unpaved sections and 65 paved sections in Brazil, are discussed. Equations predicting roughness, rut depth and gravel loss, are presented for unpaved roads. These performance parameters are a function of average daily traffic, horizontal alignment, vertical geometry, wearing course material type, maintenance and wet or dry season. Preliminary findings of analyses of roughness and rut depth on paved roads are also discussed.

The complexity of the road network/traffic load dynamic system has caused engineers and planners to use piecewise solutions to this overall systems problem. Part of the problem was the lack of information on the costs of the components of highway transportation, i.e., the costs of highway construction and highway maintenance and user costs. This is a problem which has confronted governments of developed and developing countries alike, as well as major financing agencies such as the World Bank. The current research project in Brazil was planned to respond to these needs and is sponsored by the Brazilian Government with aid from the United Nations Development Program.

The minimization of total transportation costs may be achieved by the type of model shown in Figure 1 (1). In the overall model pavement performance plays an integral and important role because it influences all the cost components of the highway model.

In the past many paved road performance relationships were developed in the United States (2), Canada (3) and Europe. These relationships are applicable to countries with well developed transportation systems, with temperature climates and pavement materials which are derived from alluvial or glacial deposits. Considerable uncertainty exists in translating these relationships directly to developing countries, particularly those in the tropics, where pavements are constructed with materials which have been influenced by tropical weathering. With the exception of the Kenya Study (4), relatively little recent research has been conducted on the performance of unpaved roads, which constitute the major proportion of the road network in developing countries. Thus a major aspect of the study in Brazil was to study unpaved, as well as paved, road performance and behavior. Elements of pavement performance and behavior which are addressed in this preliminary evaluation of the results are roughness, rut depth, gravel loss and loose material on unpaved roads and roughness, rut depth, and cracking and patching on paved roads.

Design of Experiments

The experimental design matrix for the study of unpaved roads includes four factors. These were average daily traffic, vertical alignment and horizontal curvature at two levels, and surface type at three levels, as is shown in Figure 2. The surface type materials studied were laterite, quartzite and sections without a surfacing, whose material was defined as containing more than 35 percent material passing the 0.074mm sieve. Besides the 29 sections in the main factorial, a further 19 sections were studied at intermediate levels to permit curvature relationships to be developed in regression analyses.

All the sections were used to investigate their performance under minimal maintenance, i.e., the Resident Engineers were requested to withhold blading as long as was feasible. In addition to this evaluation, 10 sections in close proximity to Brasilia for which more than one year's data had been collected under the minimal maintenance conditions, were selected to study the influence of maintenance. Each section was divided into two subsections; one subsection was bladed every two weeks and the other subsection every six weeks. Thus, in effect three maintenance policies were investigated.

Based on previous studies (4), (5) six factors were selected for study on paved roads - surfacing type, base type, average daily traffic (ADT), state of rehabilitation, age of the original surfacing or overlay with asphaltic concrete and vertical alignment. The paved road experimental design matrix, contains the six factors at two levels. Figure 3 shows the matrix and the section numbers in the

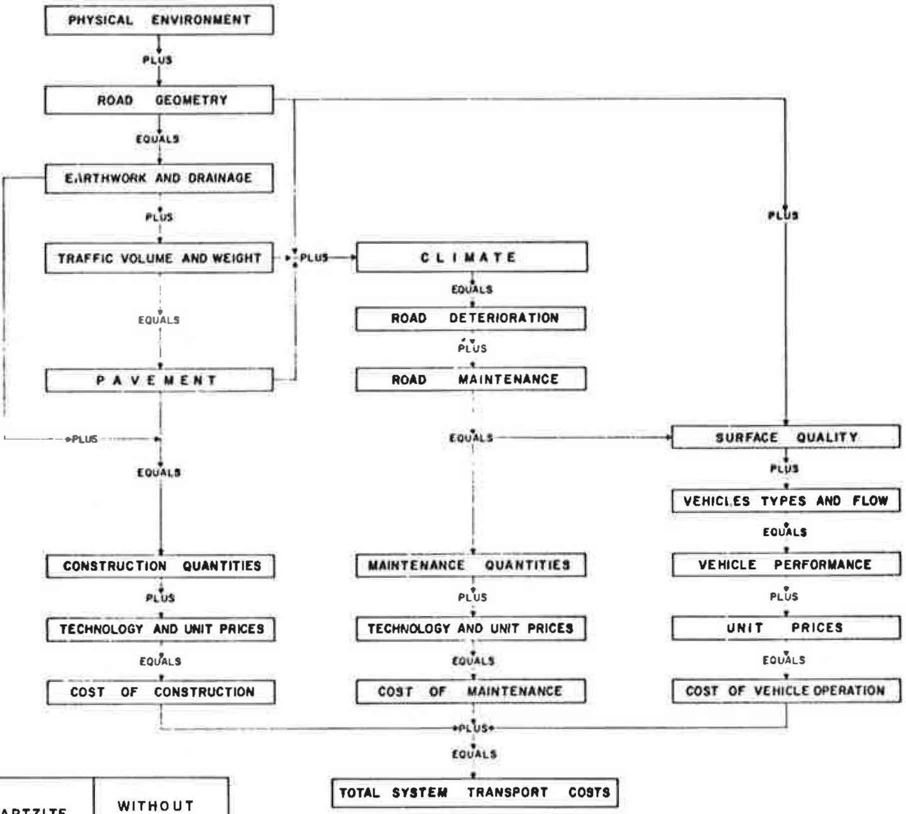


Figure 1. Flow chart for highway cost model (1)

Figure 2. Unpaved road design matrix

SURFACING MATERIAL		LATERITE		QUARTZITE		WITHOUT SURFACING	
TRAFFIC							
HORIZ. GEOM.	VERTICAL GEOMETRY	< 100	> 350	< 100	> 350	< 100	> 350
CURVE R < 250 m	≥ 6 %	203 209	312	213 215	315	217	
	0 - 1½ %	204	252 300	263	264	218	
TANGENT	≥ 6 %	206 262	253	307 261	255	205 216	
	0 - 1½ %	202	251 302	259	254 304	201	313

THE NUMBERS IN EACH CELL ARE THE SECTION NUMBERS.

Figure 3. Paved road design matrix

SURFACING TYPE			ASPH. CONC.				D. SURF. TREATM.			
BASE TYPE			GRAVEL		C STONE		GRAVEL		C STONE	
TRAFFIC (ADT.)			50-500	>1000	50-500	>1000	50-500	>1000	50-500	>1000
STATE REH.	AGE (YEARS)	V. GEOM. (%)								
OVERLAYED	≥6	≥6	128	129						
		0 - 1,5%				158		109 009		
	0 - 2	≥6		125			035	032		
		0 - 1,5%		006			034	031		
AS CONSTRUCTED	≥12	≥6		119			123 172	110 008		
		0 - 1,5%		003 113		168	173	007		
	0 - 4	≥6	022	025	151	162	002	024 111	155	103 165
		0 - 1,5%	001 021	033 112	152	161 026	004 023	106	101	102

THE NUMBERS IN EACH CELL ARE THE SECTION NUMBERS.

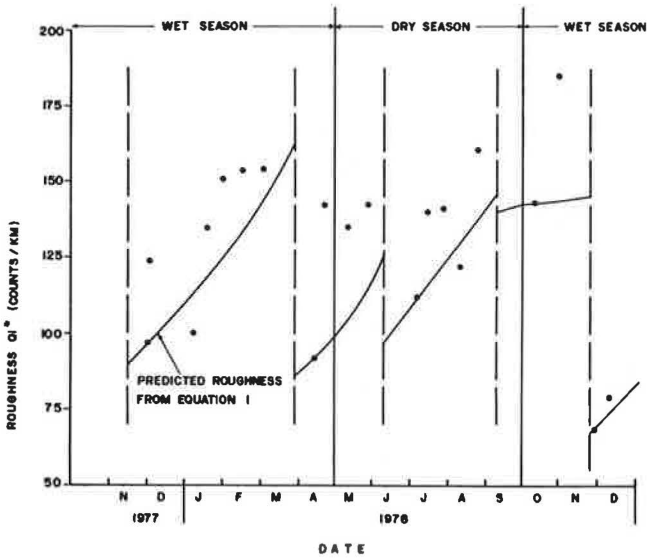


Figure 4. Roughness data points and prediction of roughness over time for section 303

Details of section 303:
ADT = 320 vpd, Grade = 3.4%, rad of curv. = 180 m
quartzite

cells which were filled. In addition to the main factorial, which contains 44 sections, a further 22 sections were selected at intermediate levels of the factors to investigate curvature relationships in the regression.

High and "nil" levels of maintenance were studied on paved test sections. Each section was divided into two; on the one subsection only filling of potholes was permitted and it was called the "nil-maintenance" subsection. A high level of maintenance on the other subsection required cracks to be slurry sealed, bad base deformations excavated and replaced and potholes excavated to a regular format and filled with an asphaltic mix.

Measurement Techniques of Dependent Variables Studied

Roughness

Two instrumentation systems were used to measure roughness in Brazil - the Maysmeter and the G.M. Profilometer. The Maysmeter is a simple, low-cost instrument designed for installation into a passenger vehicle, capable of producing an acceptable measure of roughness while traversing a road section at a normal vehicle operating speed. The Profilometer is a sophisticated and expensive device that accurately measures the profile of the road surface over which it passes. The principal function of the Profilometer, was to provide a basis for calibrating the Maysmeters. The Profilometer contains a custom built computer which simulates the passage of a quarter of a car, consisting of a body mass, tire, shock absorber and spring system, and it summates the movements of the body relative to axle as it passes over the measured road profile. This output from the Quarter-Car-Simulator (QCS) is termed the quarter-car index (QI) and has units of counts/km. A very smooth, newly constructed asphaltic concrete would have a QI value of less than 30, whereas a very rough unpaved road would have a QI greater than 200.

Calibrating the Maysmeters is essential since numerical values of roughness generated by the Maysmeter are very sensitive to the vehicle, as well as to the condition of tires, shock absorbers and springs. A set of 20 paved road sections which cover a range of roughness, were used to calibrate the Maysmeter according to the methodology developed in Texas (6). This ensured that results obtained with any of the Maysmeters in use on the Project, at any time, were compatible. This compatible roughness output, through a correlation with QI, is designated by QI* in counts/km.

Roughness results with the Maysmeter were collected by traversing each pavement study section three times, in each direction. On paved roads the test speed was standardized at 80 km/h, whereas on unpaved roads the speed had to be selected consistent with the road conditions. The highest of three possible speeds, 80 or 50 or 20 km/h, that would not cause damage to the equipment, was selected. Since the Maysmeter-QI relationship is sensitive to speed, the results obtained at alternative speeds were standardized to 80 km/h in accordance to relationships presented in (7). Measurement frequency was about four to six months on paved roads, two to three weeks on unpaved roads used in the minimal maintenance program, and every two to three days on the high frequency maintenance sections.

Rut Depth

An AASHO type rut depth gauge with a base length of 1.22 m (4 ft), which is only supported at the two extremes, was used on paved roads. On unpaved roads, because of accentuated influence of localized depressions on the readings, a cross-bar was fitted to act as a base to the A-frame. The apparatus is graduated to read rut depth with an accuracy of 1 mm. On paved roads rut depths were measured at four to six month intervals. On the unpaved roads, in the minimal maintenance program, rut depth was measured at two to three week intervals, and every two to three days on the high-frequency maintenance sections.

Gravel Loss

Regravelling is the most expensive single maintenance operation on unpaved roads, and it may be compared to overlaying a paved road in importance. Prediction of gravel loss was thus an important objective of this study. The methodology adopted was similar to that developed in Kenya (4). A grid of points 1 m apart across the road's width, and 5 m apart along the length of the road, was levelled at three monthly intervals relative to fixed benchmarks. Consequently the change in height of the grid points relative to the benchmarks was calculated over time, which, when averaged, represents a change in level of the road surface, which is the thickness of gravel lost. Since the benchmarks were fixed in the subgrade, they accommodated settlement of the section.

Loose Material on Unpaved Roads

In the Kenya study (9) the presence of loose material on unpaved roads was found to have an influence on fuel consumption. Additionally, loose material could be a predictor of gravel loss. Loose material, in millimeters, was determined by dividing the volume of loose material collected by the area over which it is collected. A steel frame, 1 m by 0,25 m, was used to delineate the area. Looseness measurements were taken across the road per 1 m width at two transverse sections within each subsection. A wire brush was used to sweep the material together, which was then poured into a measuring cylinder. Moisture contents of the loose material at each transverse section was determined in the laboratory. These measurements were taken about every two to four weeks.

Cracking and Patching

A technique (8) was developed to survey the complete section and to plot the defects and cracks on a map of the section. In this way progression of the deterioration can be followed. An AASHO type classification of the cracks was adopted as shown in Table 1, but the classification was increased to include class four cracks which represent cracks in an advanced state of deterioration. Condition surveys, which consisted of delineating and mapping each area of each crack class were carried out at about four to six month intervals. The results of the condition survey were also used to trigger maintenance.

Table 1. Definition of classes of cracks

Class of crack	Description
Class 1	Very fine cracks with a width of less than 1 mm
Class 2	Cracks with a width of 1 mm to 3 mm
Class 3	Cracks with a width greater than 3 mm
Class 4	Any width of crack which exhibits ravelling (deterioration) of the edges

Measurement Techniques of Covariates Studied

Besides the dependent variables, which are those variables for which prediction expressions are desired, and the factors of the design matrix, which are independent variables with readily determinable values, there are covariates, which are independent variables whose values are not readily controlled, and which could have an influence on the dependent variables. The covariate data collected on unpaved roads included material characteristics, number of days since last blading, blading period number since start of observations and season. In the study area there are two distinct seasons, the dry season and the wet or rainy season. Generally the dry season is from beginning April to the end of September when hardly any rain falls, and the wet season extends from beginning October to the end of April when almost all of the annual rainfall of about 1600 mm falls. On paved roads the covariates were cumulative equivalent axles, pavement structural number and pavement deflection.

Cumulative Equivalent Axles

Traffic counts as well as axle weights were required to develop cumulative equivalent axles. Historical traffic classification counts were obtained at each section. Where unavailable, this data was collected during the Project's duration. Exponential curves, using least square techniques, were fitted to the historical vehicle classification counts to facilitate later computations.

Axle weights were measured with a weigh-in-motion (WIM) system and portable scales. The AASHO axle equivalency factors for a structural number of 2.0, were used for single and tandem axles. Results presented in (10) were used for the equivalency factors of triple axles, i.e., three axles in a group. Thus on each section the average number of equivalent axles per vehicle for each vehicle class was calculated in both directions. In the calculation of the average number of equivalent axles per vehicle, it was assumed that axle weights for each vehicle class on the section had not changed since the road was constructed. Verification of replicate results collected two years apart showed that the axle weight distribution was constant, except when mining or heavy industries were newly located in the region served by the road. Combining the traffic flow relationship for a specific vehicles class with the average number of equivalent axles per vehicle permitted the calculation of cumulative equivalent axles to correspond to the time when a roughness measurement or condition survey was carried out.

Pavement Structural Number

At each section three test pits were opened. Layer thicknesses, in-situ CBR and in-situ density were measured and samples taken for the standard laboratory tests on soil samples. The resilient modulii were measured by means of the indirect tensile test on the asphaltic concrete samples (11). Structural coefficients of each layer were related to strength measurements through relationships presented in the literature (4 and 12) and which were adapted to local conditions. The structural coefficients (a_i) per inch used are as follows:

$a_1 = 0.10$ for surface treatment

$a_1 = 0.18$ for asphaltic concretes

$a_1 = 0.46(1-e^{-0,000084M_{R30}})$ for asphaltic concretes with a thickness greater than 3 cm

Where M_{R30} = the resilient modulus at 30°C in kgf/cm^2

$a_2 = (29.14CBR-0.1977CBR^2+0.00045CBR^3)x10^{-4}$ for base courses

$a_3 = 0.01+0.065\ \log_{10}CBR$ for sub-base layers or selected subgrade with an in-situ CBR greater than 40.

The structural number SN was calculated by summing the products of structural coefficient (a_i) and layer thickness (t_i) e.g.

$$SN = \Sigma a_i t_i$$

The structural number was corrected to allow for the structural support of the subgrade as follows:

$$SN^1 = SN+3.51\ \log_{10}CBR-0.85(\log_{10}CBR)^2-1.43$$

Deflection

Deflections, which could be used as a surrogate of strength, or as a measure of variability of construction of the section, were obtained with the Benkelman Beam and with a Dynaflect. The measurements were usually made at 10 points in each wheelpath in each direction on each subsection. The Benkelman Beam rebound deflection was measured under a standard 40 kN dual wheel load using 2:1 ratio beams. Measurements with both instruments were obtained every six to nine months.

Presentation and Discussion of Results

Table 2 shows the mean, standard deviation and range for the independent and dependent variables used in the unpaved and paved road analysis. The statistics for gravel loss on unpaved roads are not shown, since these are a rate, and cracking ranges from uncracked to the complete area cracked. Since large changes in the cracked condition occur summary statistics have little meaning.

Analysis of Unpaved Road Results

Roughness on Unpaved Roads. Roughness data from 30 unpaved sections which had lateritic and quartzitic gravel wearing courses were analyzed. Two regression equations were developed. The first predicts roughness as a function of time within a blading period given the roughness after blading. The second predicts the roughness after blading.

The following equation was developed for predicting roughness (QI*) given the roughness after blading.

$$\begin{aligned}\log_e(QI^*) = {} & \log_e F + D(0.00461 + 0.00477T + \\ & 0.00094G + 0.0000052ADT + 0.9832/R - \\ & 0.005777S - 0.0000055T.ADT + 0.003792T.S - \\ & 0.0000424T.F - 0.1871G/R - 0.00000535G.F - \\ & 0.0081F/R)\end{aligned} \qquad (1)$$

Where

D = number of days since last blading
F = roughness after blading (the first observed roughness after blading was used to develop equation 1)
T = type of gravel wearing course:
laterite: T = 0
quartzite: T = 1
G = absolute value of grade, in percent
ADT = average daily traffic in both directions
R = radius of curve, in m
S = season, dry season S = 0; wet season S = 1

The mean square error of the model is 0.031.

The mean roughness measurements per observation date of section 303 over a one year period are shown in Figure 4 together with the roughness prediction obtained from equation 1. In each case the first observed roughness after blading was used as input for F.

Roughness measurements were seldom taken immediately before or after blading. Therefore, equation 1 was used to predict the roughness immediately before and after blading from the first observation after blading and the last observation before blading respectively. The predicted values were used to develop the following model for roughness after blading.

$$F = 31.0 + 18.7T - 1.84G + 0.0392ADT + 14.3S + 554.7G/R + 2330.6S/R + 0.2726L \qquad (2)$$

Where

L = roughness before blading

The mean residual and the mean square error of equation 2 vary for different levels of L. For L less than or equal to 140 the mean residual, $\mu\varepsilon$, equals -11.7 and the mean square error, σ_ε^2, equals 601.3. For L greater than 140, $\mu\varepsilon$ equals 9.9 and σ_ε^2 equals 1971.6.

A series of roughness curves over time for four typical combinations of significant factors are shown in Figure 5. The roughness after blading at the start of the exercise was assumed to be 80. Equation 1 is then used to generate the roughness values until the first blading. The value for F used in the next blading period was then calculated in the following way:

$$F = F' + (\mu_\varepsilon \pm Z\sigma_\varepsilon) \qquad (3)$$

Where

F' = the first roughness predicted from equation 2

μ_ε = mean residual from equation 2 $= \begin{cases} -11.7 \text{ if } L \leq 140 \\ 9.9 \text{ otherwise} \end{cases}$

Z = normal (0,1) value

σ_ε = standard error of equation 2 $= \begin{cases} 24.5 \text{ if } L \leq 140 \\ 44.4 \text{ otherwise} \end{cases}$

This procedure was then repeated for each blading period. A distribution was used for the calculation of F since its value enters into equation 1 in a non-linear manner.

Equation 1 predicts that the increase in roughness with time within a blading period during the wet season is less than during the dry season. Under certain combinations of the significant factors during the wet season the road may in fact become smoother with time. This is caused by drivers avoiding puddles and thus following a path through the section which meanders, but avoids depressions. Roughness measurements were taken in the most prominent wheelpaths where the roughness was lower than the route through the depressions. Road width and traffic volume could influence this relationship, but even on the most heavily trafficked sections the road was sufficiently wide to permit meandering.

Rut Depth on Unpaved Roads. For the development of the models for the prediction of rut depth on unpaved road sections 30 test sections with laterite or quartzite wearing course gravel were used.

The data were analyzed in two stages. In the first stage the time effects on the change in rut depth, in millimeters, were considered and the following equation was developed:

$$\Delta\log_e(\text{rut depth}) = D\,(0.00481 + 0.00001ADT - 0.6663/R - 0.02496S - 0.00001ADT.T + 0.002749T.L + 0.01289S.T - 4.9024S/R + 0.004371S.G) \qquad (4)$$

Where

D = number of days since last blading
ADT = average daily traffic in both directions
R = radius of curve, in m
G = absolute value of grade, in percent
S = season; dry season: S=0; wet season: S=1
T = type of gravel wearing course; laterite: T=0; quartzite: T=1
L = lane; downhill lane: L=0; uphill lane: L=1

The mean square error of the equation is 0.125.

Equation 4 was then used to calculate the rut depth values at time zero for each observation, in the following way:

$$\log_e(\text{rut depth for } D=0) = \log_e(\text{rut depth at } D) - \Delta\log_e(\text{rut depth at } D)$$

The following equation was calculated for the mean rut depth, in millimeters, for D=0:

$$\text{Mean }\log_e(\text{rut depth for } D=0) = 1.447 + 0.726T + 0.00149ADT + 114.3/R - 0.1198WP + 1.021S - 106.3T/R - 0.5920T.S - 0.2093ADT/R + 0.00081ADT.S - 0.0893S.G \qquad (5)$$

Where

WP = wheelpath; external wheelpath: WP=0; internal wheelpath: WP=1

The mean square error of the equation is 0.244.

Equations 4 and 5 must be used together to predict the rut depth at any time since last blading. Figure 6 shows the data points and the rut depth calculated from equations 4 and 5 for section 303, which was selected because it had typical ranges of days since blading in both seasons.

Table 3 shows the results which were generated from equations 4 and 5 for the entire range of the significant factors. The rut depth of the internal wheelpath is not shown, but it is 8.8 percent less than that of the external wheelpath. The results for the wet season, presented in Table 3, are of a similar order of magnitude as the results obtained in Kenya (4), whereas the results in the dry season are lower than found in Kenya.

In the dry season ruts develop very slowly, and from the magnitude of the rut depth shown in Table 3, rut depth will probably not act as a trigger for maintenance. In the wet season substantial ruts develop, and thus could trigger maintenance activities. Under certain conditions the rut depth in the wet season decreases. This is probably due to the fact that drivers try to avoid water ponds and then tend to move their vehicles to drier ground. Consequently the wheeltrack position changes over time. Since rut depths were measured in the most prominent wheeltracks diminishing rut depths over time were recorded.

Gravel Loss. The prediction model for gravel

Table 2. Summary statistics related to variables studied

UNPAVED ROADS

Independent Variables	Mean	Std. Deviation	Maximum	Minimum
Average daily traffic (vpd)	236	167	608	18
Vertical alignment (%)	2.7	2.7	8.2	0.0
Horizontal curvature			Tangent	R=180m
Number of days between bladings	95	55	342	7
Cumulative traffic between bladings	24010	22120	143600	720
Dependent Variables				
Roughness (QI* counts/km)	130	63	554	35
Rut depth (mm)	18	11	55	2

PAVED ROADS

Independent Variables	Mean	Std. Deviation	Maximum	Minimum
Age at Jan. 1979				
Sections as constructed	7.9	4.4	20.5	2.5
Overlaid	5.3	4.1	12.5	0.5
Vertical alignment (%)	3.3	2.5	7.6	0
Cumulative Equiv. 80 kN axles (Jan. 1979)	1.36×10^6	3.27×10^6	20.4×10^6	0.003×10^6
Corrected structural number	5.0	0.9	7.5	3.4
Benkelman beam deflection (mm)	0.70	0.30	2.10	0.28
Dependent Variables				
Roughness (QI* counts/km)	37	15	99	15
Rut depth (mm)	3	1.6	11	0

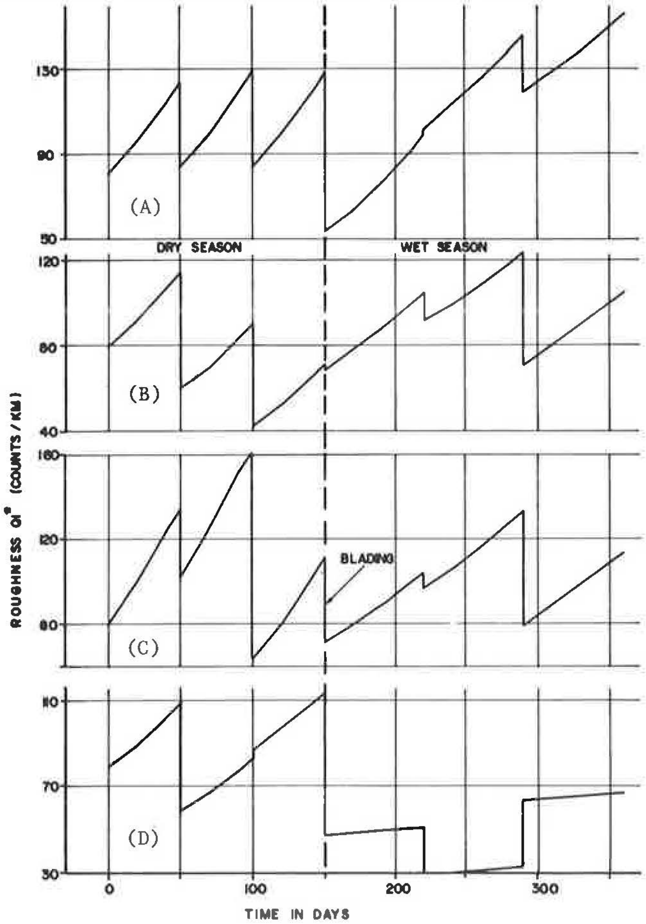
Table 3. Generated values of rut depth (in mm) in the external wheelpath on unpaved roads

SEASON	VERTICAL ALIGN	LANE	HORIZONTAL CURVATURE / CUMULATIVE TRAFFIC / AVERAGE DAILY TRAFFIC (vpd) / WEARING COURSE	LATERITE						QUARTZITE					
				20			600			20			600		
				0	2000	4000	0	30000	60000	0	2000	4000	0	30000	60000
DRY SEASON	6%	DOWN HILL	Tangent	4	7	12	10	18	31	9	15	24	22	26	32
			250 m	7	9	11	10	15	23	9	11	14	13	14	16
		UP HILL	Tangent	4	7	12	10	18	31	9	19	41	22	30	43
			250 m	7	9	11	10	15	23	9	15	24	13	17	20
	1%	DOWN HILL	Tangent	4	7	12	10	18	31	9	15	24	22	26	32
			250 m	7	9	11	10	15	23	9	11	14	13	14	16
		UP HILL	Tangent	4	7	12	10	18	31	9	19	41	22	30	43
			250 m	7	9	11	10	15	23	9	15	24	13	17	20
WET SEASON	6%	DOWN HILL	Tangent	7	14		28	51		8	55		32	79	
			250 m	11	2		26	16		8	6		20	16	
		UP HILL	Tangent	7	14		28	51		8	72		32	90	
			250 m	11	2		26	16		8			20	19	
	1%	DOWN HILL	Tangent	11	2		43	27		13	10		49	41	
			250 m	18	0		41	8		13	1		31	8	
		UP HILL	Tangent	11	2		43	27		13	13		49	47	
			250 m	18	0		41	8		13	1		31	10	

Table 4. Generated values of change in gravel level in millimeters

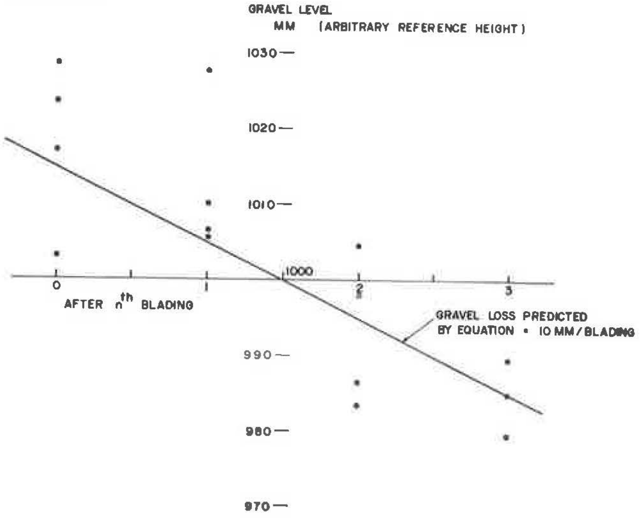
WEARING COURSE	VERTICAL ALIGNMENT	HORIZONTAL CURVATURE / NUMBER OF BLADINGS / AVERAGE DAILY TRAFFIC (vpd)	20				600			
			No blading 250 days	2 bladings	6 bladings	12 bladings	No blading 250 days	2 bladings	6 bladings	12 bladings
LATERITE	6%	Tangent	-0.4	-6.0	-17.9	-35.7	-0.4	-16.1	-48.4	-96.8
		250 m Curve	-0.4	-7.7	-23.0	-46.0	-0.4	-17.8	-53.5	-107.0
	1%	Tangent	-0.4	-1.3	-3.9	-7.7	-0.4	-11.5	-34.4	-68.7
		250 m Curve	-0.4	-3.0	-9.0	-18.0	-0.4	-13.2	-39.5	-79.0
QUARTZITE	6%	Tangent	-0.4	-6.0	-17.9	-35.7	-0.4	-16.1	-48.4	-96.8
		250 m Curve	-0.4	-14.2	-42.6	-85.2	-0.4	-24.4	-73.1	-146.2
	1%	Tangent	-0.4	-1.3	-3.9	-7.7	-0.4	-11.5	-34.4	-68.7
		250 m Curve	-0.4	-9.5	-28.6	-57.2	-0.4	-19.7	-59.1	-118.2

Figure 5. Roughness curves over time generated from the roughness prediction model for unpaved roads



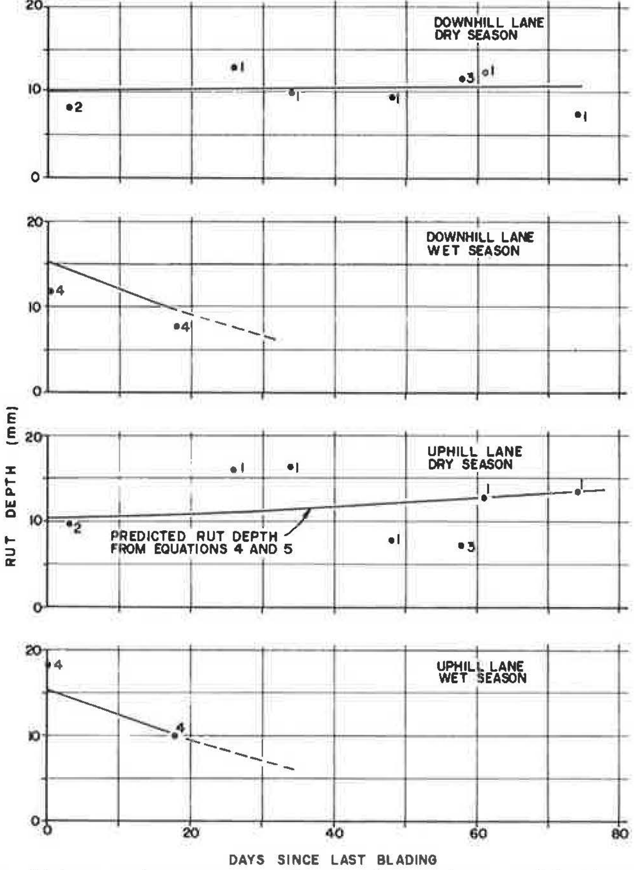
Note: blading every 50 days in dry season and every 70 days in wet season.
(A) quartzite, grade = 6%, ADT = 600 vpd, tangent
(B) quartzite, grade = 1%, ADT = 20 vpd, curve = 250 m
(C) laterite, grade = 6%, ADT = 600 vpd, tangent
(D) laterite, grade = 1%, ADT = 20 vpd, curve = 250 m

Figure 7. Gravel level as a function of the number of bladings



Legend: each data point is the mean gravel level of row 2 per subsection-lane.

Figure 6. Rut depth versus time since last blading for section 303



Note: number next to data point refers to blading period number.
Details of section 303: ADT = 320 vpd, grade = 3.4%, rad of curv. 180 m, quartzite.

Figure 8. Roughness versus age for paved test sections with SN' in the range of 4 to 5

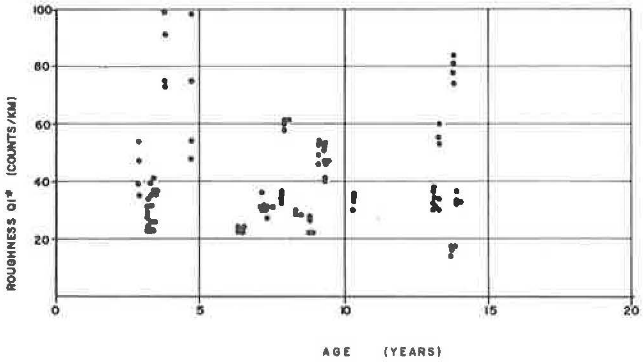
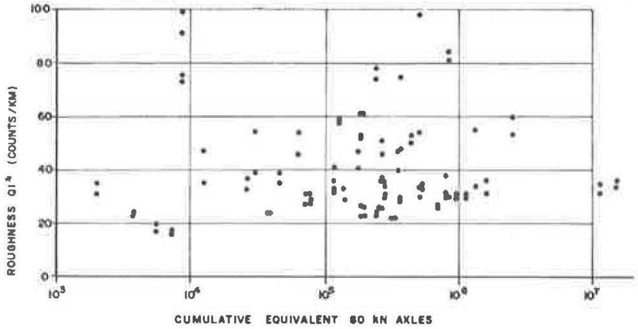


Figure 9. Roughness versus equivalent axles for paved test sections with SN' in the range of 4 to 5



loss was developed from data collected on 30 sections with laterite or quartzite wearing course gravel. The periods between bladings on these sections ranged from 14 to 250 days over an 18 month observation period. The equation can be applied to sections that receive maintenance in the form of blading, or that are left without blading.

The following is the prediction model for the change in gravel height, in millimeters:

$$\text{Change in gravel height} = B\,(-0.0046ADT - 213.8/R - 0.4670G - 816.6T/R - 0.0043ADT.R_2 - 0.0082ADT.R_3) + D\,(0.0580 - 0.0461R_2 - 0.1322R_3) \quad (6)$$

Where

B = number of bladings

ADT= average daily traffic in both directions

R = radius of curve in m

G = absolute value of grade in percent

T = wearing course material type, laterite: $T=0$ quartzite: $T=1$

D = time in days since last blading or start of observation period
- $D = 0$ if the section has been bladed, i.e., if $B > 0$
- $D > 0$ if the section has not been bladed, i.e., if $B = 0$

R_2= transverse location variable
- R_2= 1 if location is 2 m from the road edge
- R_2= 0 otherwise

R_3= transverse location variable
- R_3= 1 if location is 3 m from the road edge
- R_3= 0 otherwise

The mean square error of the model is 361.6.

Measurements taken in the external three rows of each subsection-lane, starting 1 m from the road edge, were used to analyze the influence of transverse location on gravel loss. $R_2 = R_3 = 0$ corresponds to the most external row, row one, located 1 m from the road edge. Row two is 2 m and row three is 3 m from the road edge.

Equation 6 can be used for the prediction of gravel loss for two different situations. If the road is bladed then B is set to the number of bladings and D is set to zero. The predicted change in gravel height represents the total gravel loss caused by blading, weathering and traffic. Although the model is a function of the number of bladings, it can be used in terms of a unit time by considering the number of bladings per unit time. If the road is not bladed then B is set to zero and the model becomes a function of time in days. Therefore, the first part of the equation should be applied in periods when the section is bladed and the second part used before blading has started or after it has terminated.

Equation 6 demonstrates that without blading there is a movement of gravel from the middle of the road towards the external row with time.

A plot showing the gravel loss model for row two for the combination of factors exhibited by section 257, together with the data points of section 257, is shown in Figure 7. Since gravel loss is a rate, the model was centred through the mean number of bladings and the mean arbitrary gravel level. This section received three bladings during the observation period, and the observations were taken between bladings.

The primary objective of predicting gravel loss is to program regravelling. The mean change in gravel height over a section was derived from equation 6 by combining the three rows.

$$\text{Mean change in gravel height} = B\,(0.0088ADT - 213.8/R - 0.4670G - 816.6T/R) - 0.00143D \quad (7)$$

Equation 7 predicts the mean change in gravel height after B bladings, or if no bladings are applied, after D days. This equation was used to generate changes in gravel height for 2,6 and 12 bladings, and over a 250 day period when no maintenance was applied, as shown in Table 4 for the ranges of significant factors.

The mean gravel loss is dependent on the number of bladings rather than time or cumulative traffic as is generally reported in the literature. Consequently a direct comparison to published results is not possible. The results in Table 4, up to six bladings, are of a similar order of magnitude as found in Kenya (<u>4</u>), assuming that the bladings occurred within a one year period. Lund (<u>13</u>) supports the finding that maintenance is correlated with gravel loss. His observations were that the quality of maintenance probably plays an important role on gravel loss. This was an aspect which was not studied in the present Project, and the relationships presented are deemed to consider average maintenance standards as were generally applied in the study region.

Loose Material. A preliminary analysis of the data collected shows that the thickness of loose material within 2 m from each road edge is considerably larger than the thickness over the rest of the road width. The results obtained at different cross-sections locations within a section are not significantly different, and consequently the test procedure was standardized to take measurements at two cross-sections per subsection. The time effect on the thickness of loose material was found to be strong, and could be caused by the influence of moisture content of the loose material. Further work is continuing to develop predictive equations for loose material.

Analysis of Paved Road Results

The design of experiments for the paved road analysis was structured to permit two types of analysis, viz of the time effect and of traffic, geometric and pavement characteristics. In the analysis of time effects the change in the dependent variable, e.g. roughness, rut depth or cracking and patching, is studied for each section during the observation period. An analysis of traffic, geometric and pavement characteristics permits an evaluation of these factors shown in Figure 3, together with directional and maintenance effects, on the dependent variables.

It is important to note that the paved road analysis is still in the preliminary stages, but that there are interesting initial observations and also some problems.

Roughness on Paved Roads. Preliminary analyses of the time effects showed that:

1. The steeper the grade, the greater the increase in roughness with time. The change in roughness over time was not significantly different for the uphill and downhill directions on any grade.
2. The increase in roughness over time on a section constructed with a crushed stone base is

greater than for a section constructed with a gravel base. In some cases the material classified as crushed stone was of a poorer quality than would be expected with crushed stone, and this could influence the finding.

3. Changes in roughness with time on the two maintenance subsections were not significantly different.

In the analysis of the main factors the mean roughness over time on the two subsections of each section were not significantly different. Certain problems have become apparent through the cross section analysis. For a corrected structural number of 4 to 5 the range of roughness is almost independent of age, as may be seen from Figure 8. In some cases an old road has the same roughness as a new road. This situation remains similar when age is substituted by equivalent axles as is shown in Figure 9 because of the high correlation between age and cumulative equivalent axles.

Sections which have carried large numbers of equivalent axles are often smoother than sections which have carried a low number of equivalent axle repetitions, because thicker pavements were designed for heavily trafficked roads. This situation presents problems in separating the structural number and cumulative equivalent axles effects.

Analysis techniques which are expected to overcome these problems associated with cross section analysis are presently being applied to develop performance models.

Rut Depth on Paved Roads. Initial analyses of the time effects indicated that:

1. The increase in rut depth with time on old pavements is faster than on newly constructed or newly overlaid sections.
2. On sections less than four years old, the increase in rut depth is greater for sections with a gravel base than for sections with a crushed stone base.
3. On sections less than four years old the increase in rut depth is greater for sections with an asphaltic concrete surfacing than a surface treatment.

In the analysis of the main factors similar confounding effects were found as elaborated above for roughness.

Cracking and Patching. Preliminary evaluation of the percentage area of the test section which exhibits class 1 to 4 cracking shows that the total area which is cracked is considerably larger for as-constructed roads with an asphaltic concrete surfacing than for sections with a surface treatment or sections which were overlaid. Further analysis of this dependent variable is continuing.

Conclusions

After a two year study period preliminary results of the performance of unpaved and paved study sections on in-service roads in the central and southeast regions of Brazil were presented.

The development of roughness on unpaved study sections over time within a blading period was related to the average daily traffic, vertical geometry, horizontal alignment, wet or dry season, lateritic or quartzitic wearing course gravel and the roughness after blading (Equation 1). A further model (Equation 2) was developed which predicts the roughness after blading as a function of roughness before blading, vertical geometry, horizontal alignment and wet or dry season. Generation of road roughness over time can then be a accomplished by using equations 1 and 2 with a normal distribution of the residuals of equation 2.

The prediction equation for rut depth on unpaved roads also consists of two models; one predicts the development of rut depth over time and the other predicts the rut depth after blading. In addition to the significant factors found for roughness, lane and wheelpath effects were found to be significant.

The change in gravel height was found to depend on the number of bladings, average daily traffic, horizontal alignment and material type. The presented model for roughness shows that it is necessary to blade the road to maintain a desired roughness level, and the gravel loss model indicates that by blading, gravel is lost. This finding requires that optimization techniques be used to program maintenance.

The paved road analysis was still very preliminary and some preliminary observations, as well as problems related to analysis of the main factors were presented. Several analysis techniques are being evaluated to overcome the problems related to cross section analysis.

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