CHAPTER 4 - UNPAVED ROAD ROUGHNESS ANALYSIS

4.1 INTRODUCTION

Road maintenance in the form of blading has the greatest influence on the roughness-time curve; consequently, two blading strategies were evaluated. The first consisted of withholding blading for as long as possible on all 48 unpaved study sections because of difficulties in the control of blading operations. The second strategy consisted of selecting ten study sections in the vicinity of Brasília, each of which was divided into two subsections. Under this strategy one subsection was bladed every two weeks, whereas the other subsection was bladed every six weeks. Table 4.1 contains the dependent and independent variable statistics for the roughness studies, and these statistics aid in placing in perspective the inference space within which the models were developed.

4.2 APPROACH FOR UNPAVED ROUGHNESS ANALYSIS

The period between bladings was considered a cycle since every time an unpaved road was bladed, the roughness was generally reduced and the new deterioration during the cycle depended on the length of time between bladings. Consequently, deterioration was considered a function of the number of days since the last blading. In the Kenya study (Hodges, Rolt and Jones, 1975) the same approach was used, but in that study they assumed that blading a road returned its roughness to some standard value. Inspection of the data collected in Brazil showed that the roughness measured after blading varied, so that the assumption of a standard value would not be appropriate. Because roughness after blading was variable, and the number of days between blading varied widely, the analysis was executed in two parts: the first part consisted of predicting the change in roughness with time, while the second part involved predicting the roughness after blading.

The choice of the form of the deterioration model was based on considerations of the interaction of a vehicle with a road. When a road is very smooth with no surficial irregularities, a vehicle imparts forces which are similar to its static loading. Then, as the first irregularities develop from traffic and weathering, increased

TABLE 4.1 - UNPAVED ROAD DATA SUMMARY (Continued)

Variable	Mean	Standard Deviation	Range	
			Minimum	Maximum
Number of sections = 48				
Grade (%)	3.8	2.6	0.0	8.2
Curvature (1/Rad) on curved sections	.0039	.0009	.0025	.0055
Road width (m)	9.8	1.09	7.0	12.0
MATERIAL PROPERTIES				
Percentage passing the 0.42 mm sieve	53	22	24	98
Percentage passing the 0.074 mm sieve	36	24	10	97
Plasticity index (%)	11	6	0	33
Liquid Limit (%)	32	9	20	62
AVERAGE DAILY TRAFFIC (both directions)				
Passenger cars	88	64	11	288
Buses	7	7	0	29
Pickups	37	29	4	115
Two axle trucks	56	93	1	435
Trucks and trailer combinations with more than 2 axles	15	18	0	66
TIME RELATED INFORMATION FOR GRAVEL LOSS				
Number of observations	604			
Time of observation relative to start of observation or regravelling (days)	238	211	0	1099
Number of bladings relative to start of observation or regravelling	2.3	3.3	0	23

TABLE 4.1 - UNPAVED ROAD DATA SUMMARY (Conclusion)

Variable	Mean	Standard Deviation	Range	
			Minimum	Maximum
INFORMATION RELATED TO ROUGHNESS MEASUREMENTS				
Roughness (QI* counts/km)	117	61	15	445
Number of days since blading for the last observation in each blading period	75	70	1	661
Number of vehicle passes since blading for the last observation in each blading period	16080	17880	63	136460
INFORMATION RELATED TO RUT DEPTH MEASUREMENTS				
Rut depth (mm)	11.1	8.6	0	75
Number of days since blading for the last observation in each blading period	61	66	1	661
Number of vehicle passes since blading for the last observation in each blading period	12490	14030	21	86700

dynamic forces are imposed on the road with resultant deterioration and a rapid increase in roughness. At the upper end of the roughness scale it is unlikely that a road will continue to increase in roughness, but rather that at a very high roughness level, the vehicles slow down and there is hardly any change in roughness. In fact, if all conditions of traffic and weather remain constant, virtually the same roughness will be maintained.

In addition to the macro-development of roughness, as described above, there is also the micro-development of roughness associated with the period immediately following a blading. This usually occurs within the first few days after blading, and although no data on this aspect was collected, a possible deterioration mechanism is postulated for completeness. The mechanism is probably different for the dry and rainy seasons. In the dry season the loose material is scraped from the side drains and is pulled over the road filling the depressions and acting as a blanket to retard the abrasive action of tires on the surfacing. However, because the moisture content is generally low, there is nothing to bind the material and consequently within a relatively small number of vehicle passes most of the material will again be displaced into the side drain. This means that there will be a rapid increase in roughness until most of the loose material has been dislocated, and then the rate of roughness development will reduce to the long term rate. Although bringing in loose material from the side drain was accepted practice in the study area, it should be noted that an alternative maintenance philosophy exists, namely all loose material is bladed off the road since it is claimed that loose material acts as a grinding paste and adds to abrasion and gravel loss. It is likely that each philosophy is applicable to specific material types, and this remains an area for further study.

When blading in the wet season, loose material is also brought in from the side drains and sometimes the existing road surface is cut to eliminate high spots and to generate material to fill in the low spots. Usually sufficient moisture is available that the material is not displaced into the side drains and is compacted under traffic. However, an uneven thickness of loose material across the road width results in depressions under traffic compaction. Therefore, initially there is a fairly rapid development of roughness as vehicles seek out the smoothest path through a section, and thereafter, once this path has been developed, the roughness is slightly lower than before and the road deteriorates at the long term deterioration rate.

In selecting a model type that could represent the deterioration curve there were two important restrictions, namely: (1) that the model form could be linearized to accomodate the large number of deterioration cycles studied in a linear regression technique; and (2) that the data would permit the development of the model.

Inspection of the data showed that the rate of increase in roughness with respect to time or traffic is a function of the current roughness level (QI*), not of the initial roughness level after blading (QI^*_o) as some engineers may suggest. This means:

$$\frac{dQI^*}{dt} = f\,(QI^*)$$

Both the logit and exponential models possess the above property, although they are not the only ones.

A first model type is the typical s-shaped or logit curve. This has the general form of:

$$QI^* = QI^*min + (QI^*max - QI^*min)/\{1 + EXP(-t.f)\}$$

where

QI* = roughness;
t = time;
f = regression function which is a linear combination of independent variables.

The major disadvantage of this type of model is the fact that it is symmetrical about (QI*max - QI*min)/2, and that its maximum rate of change of roughness is also at this point rather than at some higher roughness level as is expected.

This model does have the benefit that it can be linearized readily. In addition, QI*max and QI*min are actual limits of roughness, which are respectively 450 and 15 as observed during the study period and were thus used in the development of the prediction model.

Another model type that could readily fit the hypothesized deterioration curve is a piecewise combination of two exponential type curves. However, inspection of the data showed that very little data existed in the range from 300 to 450 QI*, and thus the piecewise combination of two curves became unfeasible. Because of the absence of extensive data in the higher roughness range an exponential curve which would have a similar shape as the logit curve in the low roughness range but would then continue increasing indefinitely, could fit the data adequately. An artificial upper limit at 450 QI* would make the model practical. The general form of the exponential model is:

$$QI^* = EXP\,(f1 + t.f)$$

where f1 = regression function, a linear combination of independent variables and the other variables are as previously defined.

The advantage of both the logit and the exponential model is that since the standard deviation of roughness is related to the magnitude of the roughness a logarithmic transformation results in homogeneous variances for the regression analysis. Both models were selected for evaluation as described below.

For the development of a prediction model for the roughness after blading, a logarithmic transformation of both the roughness before and after blading was deemed necessary to homogenize variances. The greater the measured roughness, the greater was the observed standard deviation of observations. The roughness after blading was then evaluted as a linear combination of the roughness before blading and material property effects and section characteristics.

4.3 ANALYSIS OF CHANGE OF ROUGHNESS WITH TIME

Two functional forms of the roughness-time relationship were evaluated, namely, an exponential and a logit relationship. In both these relationships the regression function was assumed to be a linear combination of the independent variables. The following independent variables were evaluated: (1) grade of road; (2) radius of curvature; (3) liquid limit of surfacing material; (4) plasticity index of surfacing material; (5) percentage of surfacing material passing the 0.42 mm sieve; (6) percentage of surfacing material passing the 0.074 mm sieve; (7) average daily traffic of each of five vehicle classes: cars, pickups, buses, two axle trucks and other trucks; (8) uphill or downhill lane; (9) road width; (10) wet or dry season; (11) qualitative surfacing type descriptors, *e.g.* laterite, quartzite or clay; and (12) time in days since the most recent blading.

The generalized linear model (GLM) procedure of the SAS statistical package (SAS Institute, 1979) was used to evaluate the significant effects. Since the objective of this analysis was to determine the rate of change of roughness, the intercept terms were removed by centering the data through the mean time within each cycle between bladings. Then , one two factor interactions of the other independent variables with time were investigated.

The following independent variables were found significant in the exponential model:

$$\begin{aligned} LDQ = D\{&0.4314 - 0.1705T2 + 0.001159\ NC \\ &+ 0.000895\ NT - 0.000227\ NT \times G \\ &+ S\ (-0.1442 - 0.0198\ G + 0.00621\ SV \\ &- 0.0142PI - 0.000617\ NC)\} \end{aligned} \tag{4.1}$$

where

LDQ = change in natural logarithmic value of roughness (QI* counts/km);

D = number of days since last blading in hundreds, *i.e.*, time/100;

T2 = surfacing type dummy variable:

T2 = 1 if surfacing is clay;

T2 = 0 otherwise.

NC = average daily car and pickup traffic in both directions;

NT = average daily bus and truck traffic in both directions;

G = absolute value of grade in percent;

S = season dummy variable:

S = 0 if dry season,

S = 1 if wet season;

SV = percentage of surfacing material passing the 0.074 mm sieve;

PI = plasticity index of surfacing material (%)

The t-values of each coefficient are given in Table 4.2. This model has an R-squared value of 0.26, and the sample size was 8276.

The confidence interval (CI) relates to that of predicting one future value, in this case the roughness of a 320 m section, and is as follows for the large sample sizes employed:

$$CI = \hat{y} \pm 2.01\ s\sqrt{1+\frac{1}{n}}$$

where

$\hat{y}$ = predicted value;

s = standard error of the prediction model;

n = number of observations in the sample used to develop the prediction model, which is very large for the models and thus 1/n is approximately zero.

For a standard error of the model of 0.222, approximate 95% confidence intervals are LDQ + or - 0.433 for the logarithmic value of the change in QI*, or from 0.65 to 1.54 per unit change in QI*. Thus, if equation (1) predicts a change in roughness of 100, the true value of the change falls between 65 and 154 with 95% confidence.

Note that although the R-squared value is relatively low, a very large number of observations were taken, so the equations are statistically highly significant. Another contributory factor to the relatively low R-squared value is the large variability in roughness across the road width and within the relatively short road sections

TABLE 4.2 - REGRESSION ANALYSIS OF THE CHANGE IN ROUGHNESS (IN QI*) WITH TIME

Parameter	Estimate	Standard Deviation	t-value
D	0.4314	0.0250	17.26
D x T2	-0.1705	0.0258	-6.60
D x NC	0.001159	0.000155	7.46
D x NT	0.000895	0.000087	10.22
D x NT x G	-0.000227	0.000049	-4.65
D x S	-0.1442	0.0463	-3.11
D x S x G	-0.0198	0.0051	-3.87
D x S x SV	0.00621	0.00073	8.43
D x S x PI	-0.0142	0.0021	-6.75
D x S x NC	-0.000617	0.000199	-3.10

that were studied. This meant that the Mays Meter vehicles, although attempting to follow the same wheelpath through a section, were not always successful. Finally, a high R-squared value means that there is a precise relation between dependent and independent variables. We know that in the unpaved road studies the wheeltracks moved to different lateral positions as the vehicles found more desirable paths in terms of roughness or rut depth than the previously used paths. This means that the roughness could decrease or increase from one time to the next, without maintenance. The regression model thus depicts what happens on the average to the roughness on unpaved roads.

One of the major objectives of the regression analysis was to determine the relative influence of different vehicle types on the development of roughness. Unfortunately, a number of sections had no truck other than two axle or bus traffic, with the result that these vehicle type average daily traffic figures affected the residuals only on a few specific sections. As a consequence, the regression coefficients were either of the wrong sign, or they were disproportionately larger or smaller when compared with the other vehicle types. Cars and pickups were also highly correlated, as would be expected, since the proportions of these two vehicle types were fairly constant. Consequently, only the two vehicle groups, cars and pickups, and buses and trucks, termed cars and trucks respectively, were found to be meaningful.

Another regression model in which the average daily traffic was substituted for the two traffic classifications, was evaluated. This model had an R-squared value which was significantly smaller, at the 0.01 level, than the R-squared of model (4.1). Therefore the hypothesis that the coefficients of the two traffic classifications in model (4.1) are equal is rejected. However, the confidence interval for this new model is not meaningfully larger than that of model (4.1), and therefore care should be taken in the application of equivalency factors between the two vehicle types.

Model (4.1) predicts an increase of roughness with time even in the absence of traffic. This effect is reduced on roads classified as having a clay surface. This is believed to be the result of binding of the surfacing which is not adequately described by liquid limit, plasticity index or percentage of the surfacing material passing the 0.074 mm sieve. Other effects are as follows:

1 - Both the average daily car and truck traffic are positively correlated with the rate of change of roughness on the level road and the effects are very similar, *i.e.*, one truck passage increases the roughness approximately as much as one car pass. On grades, the truck influence is reduced and on a four percent grade, the truck influence is zero. This is possibly attributable to low truck speeds on the grade since the sections were generally 720 m in length, and that the trucks compact the surfacing, and even tend to smooth out unevenness. At the lower truck speeds, abrasion of the surfacing may also be lower than at higher speeds.

2 - In the wet season, the development of roughness is lower than in the dry season. On grades, the rate of roughness development is further reuuced, probably because of better drainage. Transverse erosion was minimal on grades greater than 5%. In these cases where longitudinal erosion occurred vehicles avoided it and there was thus no influence on roughness.

3 - The influence of cars is reduced in the wet season to such an extent that one truck passage is equivalent to 1.7 car passages on the level road. On grades, truck influences are again reduced compared to the level stretches, as occurs during the dry season.

4 - Surfacing material characteristics are important in the wet season. Increasing the material passing the 0.074 mm sieve increases the rate of roughness development, whereas an increase in the plasticity index has an opposite effect. Historically clay has been added to sand to enhance the wearing characteristics, and thus is reflected in the model, since clay has a higher PI than sand. From experience, in the wet season a low percentage of fine material, and consequently a low plasticity index, is beneficial. For the percentage of surfacing material passing the 0.074 mm sieve greater than 2.28 times the plasticity index, the model predicts an increase in roughness in the wet season, all other factors being constant.

Model (4.1) predicts the development of roughness in terms of inter alia wet or dry season. For the central plateau region of Brazil where the study was executed, this type of differentiation may be sufficient, but problems are possible when the model is extrapolated to other regions in Brazil, or to other countries. Consequently a further analysis was run in which actual rainfall data was used. From the logistics involved it was not possible to maintain a rain gauge at every test section. Instead, the rainfall data collected by the Meteorology Department of the Ministry of Agriculture at permanent recording stations were used. In the unpaved study region there were seven recording stations. The distances from the stations to the test sections were less than generally accepted as the influence radius of a station. However, because of the distances from the stations, microclimate influences were undetermined and an averaging of the rainfall data occurred. In addition to the factors evaluated for Model (4.1), the cumulative rainfall since the last blading was considered. The following variables were found to be significant:

$$LDQ = D(0.3759 - 0.1010T2 + 0.000320NC + 0.001015NT) + CRF(-0.00016 - 0.0000354G + 0.00000883SV - 0.0000218PI) \quad (4.2)$$

where CRF = cumulative rainfall since the previous blading, in mm, and the other variables are as defined for Model (4.1). Model (4.2) has an R-squared value of 0.31, a standard error of 0.236 and the sample size was 8276. The t-statistics of each coefficient are given in Table 4.3.

The R-squared value of model (4.2) is larger than that for Model (4.1) since a different analysis method was employed to accommodate the cumulative rainfall. On the other hand, the standard error is larger than for Model (4.1), but this difference is not considered to be meaningful.

The inclusion of rainfall substituted adequately for the season dummy variable used in Model (4.1). Furthermore, the coefficients of Model (4.2) excluding rainfall effects are similar to those of Model (4.1) for the dry season. Two traffic terms found significant in Model (4.1) became non-significant when rainfall was

TABLE 4.3 - REGRESSION ANALYSIS OF THE CHANGE IN ROUGHNESS (IN QI*) WITH TIME, INCLUDING RAINFALL

Parameter	Estimate	Standard Deviation	t-value
D	0.3759	0.0156	24.13
D x T2	-0.1910	0.0162	-11.81
D x NC	0.000320	0.000072	4.47
D x NT	0.001015	0.000073	13.98
CRF	-0.000160	0.000045	-3.56
CRF x G	-0.0000354	0.0000052	-6.79
CRF x SV	0.00000883	0.0000008	11.46
CRF x PI	-0.0000218	0.0000022	-10.10