CHAPTER 6 - UNPAVED ROAD RUT DEPTH ANALYSIS

6.1 INTRODUCTION

Users of unpaved roads claim that deep ruts affect the safe operation of vehicles, and can lead to accidents. In addition, prominent ruts act as drainage channels and prevent water from running off the roadway, thus causing drainage problems which could lead to rapid deterioration of the riding quality or the road becoming impassable. The responsible agency therefore needs to know when to program maintenance in terms of the developed rut depth. The rut depth studies were aimed at predicting rut depth at any point in time, in both the wet and dry seasons. A data summary of the dependent and independent variables studied are given in Table 6.1. These statistics aid in defining the inference space in which the models were developed.

6.2 APPROACH FOR RUT DEPTH ANALYSIS

A deterioration cycle for rutting starts following a given blading and continues until the next blading. Thus a deterioration cycle is a short term phenomenon, and it was possible to make observations during a number of cycles during the study period. The amount of deterioration was a function of the length of time between bladings. Inspection of the data showed that, contrary to general belief, rut depth after blading was not zero. This agreed with the Kenya study (Hodges, Rolt and Jones, 1975) where models predicted a non-zero rut depth after blading. Because the rut depth after blading was variable, and the number of days between bladings varied widely, the analysis was executed in two parts: the first part consisted of predicting the change in rut depth over time, while the second part addressed predicting the rut depth after blading. A combination of the two parts predicts the rut depth as a function of time since blading and other independent variables.

6.3 ANALYSIS OF THE CHANGE IN RUT DEPTH WITH TIME

The rate of change in rut depth was hypothesized to be a function of a linear combination of the independent variables. This model form was selected since the development of rut depth appeared

TABLE 6.1 - 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 6.1 - 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

to be independent of the existing rut depth for the available data. The following independent variables were investigated: (1) horizontal alignment; (2) grade; (3) liquid limit and (4) plasticity index of surfacing material; (5) the percentage of the surfacing material passing the 0.42 mm and (6) the 0.074 mm sieve; (7) qualitative surfacing type descriptors, *e.g.*, laterite, quartzite and clay; (8) average daily traffic in both directions for five vehicle classes: cars, pickups, buses, two-axle trucks and other trucks; (9) internal and external wheelpath; (10) uphill or downhill lane; (11) road width; and (12) seasonal effects. Two factor interactions of these independent variables and time were also studied. The dependent variable investigated was the change in rut depth in mm. Because of variations in periods between bladings, and also in the rut depths after bladings, the analysis was conducted by centering the data within each blading period through the origin. This procedure allows the determination of the change of rut depth without the influence of the rut depth after blading. The GLM procedure of the SAS package (SAS Institute, 1979) was again used to perform the regression analysis.

Initially, two season parameters, representing wet and dry seasons, were used. A preliminary model predicted decreases in rut depth over time on most sections during the wet season. Inspection of the data showed that at the start of the wet season a rapid decrease in rut depth occurred. This continued for the first two months of the season, or until the section was bladed. It was postulated that this phenomenon was a result of drivers avoiding the ruts where water was ponding, and thus the ruts decreased. Therefore, a third season descriptor, transition season, was introduced. The significant variables for the change in rut depth (DRD in mm) with time are shown in the models for the three seasonal conditions:

Dry season (S1 = 0, S2 = 0)

$$\begin{aligned} DRD = D(&9.78 - 1.033G - 0.192PI - 3.63T2 + 0.0302NC \\ &+ 0.0198NT - 3.27RO - 3.04NT/R \\ &+ 0.46G \times RO - 325.0L/R + 0.0364L \times SV) \end{aligned} \tag{6.1 a}$$

Transition season ($S1 = 1$, $S2 = 0$)

$$DRD = D(-83.76 + 3.658G - 0.192PI - 3.63T2 - 0.1147NC + 0.1249NT - 3.27RO - 3.04NT/R + 0.46G \times RO - 325.0L/R + 0.0364L \times SV + 6.874W) \quad (6.1\ b)$$

Wet season ($S1 = 0$, $S2 = 1$)

$$DRD = D(9.78 - 1.033G - 0.192PI - 3.63T2 - 0.0109NC + 0.0198NT - 3.27RO - 3.04NT/R + 0.46G \times RO - 325.0L/R + 0.0364L \times SV) \quad (6.1\ c)$$

where

D = time since last blading, in days/100;
G = absolute value of grade, in percent;
PI = plasticity index, in percent;
T2 = surfacing type dummy variable:
  T2 = 1 if surfacing is clay,
  T2 = 0 otherwise;
NC = average daily number of cars and pickups in both directions;
NT = average daily number of buses and trucks in both directions;
RO = wheelpath dummy variable:
  RO = 0 for external wheelpath,
  RO = 1 for internal wheelpath;
R = radius of curve, in m;
L = lane dummy variable:
  L = 0 for uphill lane,
  L = 1 for downhill lane.

S1 = transition from dry to wet season dummy variable: first two months of wet season or until first blading in this period, S1 = 1, otherwise S1 = 0;

S2 = wet season dummy variable: after first blading in first two months of wet season, or after two months in wet season, S2 = 1, otherwise, S2 = 0;

W = road width, in m.

The t-values of each coefficient are given in Table 6.2. This model has an R-squared value of 0.14, a standard error of 4.87 and 7957 observations were used in the regression analysis. The 95 percent confidence intervals are DRD + or - 9.50. The R-squared value is low because of the variations in the position of the ruts resulting in measured rut depths which are variable and thus do not correlate highly over time. The model depicts an average condition of the ruts. In addition, a very large data base was used and the model is statistically highly significant.

As a check for the robustness of the coefficients of the traffic terms, a further analysis was run using the average daily traffic as the only traffic term. The resultant model had an R-squared of 0.12, which is significantly lower than for model (6.1) at the 0.01 level. Therefore, the hypothesis that the coefficients of the two traffic classifications are equal is rejected.

Equation (6.1) predicts an increase in rut depth with time for both cars and trucks in the dry season, and the influence of one car passage is equivalent to 1.5 truck passages. On curves one car passage is equivalent to more than two truck passages, depending on the radius of curvature. These phenomena are attributed to a wider influence area of especially dual truck wheels compared to car wheels, and also since trucks do not necessarily travel with their wheels completely in the ruts,thus compacting and displacing material into the wheeltracks. In the wet and transition seasons the relative influences of cars and trucks change. Car traffic results in a decrease in rut depth, probably because they avoid the existing ruts, whereas truck traffic has a significant positive effect, probably because of their compaction and movement of the surfacing material. In the transition season the coefficient of time is large and negative, signifying a large rate of reduction in rut depth, but this effect should be considered in conjunction with the term containing

TABLE 6.2 - REGRESSION ANALYSIS OF THE CHANGE IN RUT DEPTH (IN mm) WITH TIME

Parameter	Estimate	Standard Deviation	t-value
D	9.78	1.52	6.42
D x G	-1.033	0.292	-3.54
D x PI	-0.192	0.049	-3.94
D x T2	-3.63	0.92	-3.93
D x NC	0.0302	0.0027	11.33
D x NT	0.0198	0.0034	5.86
D x RO	-3.27	0.83	-3.95
D x NT/R	-3.04	0.99	-3.07
D x G x RO	0.46	0.18	2.57
D x L/R	-325.0	93.1	-3.49
D x L x SV	0.0364	0.0093	3.90
D x S1	-93.54	13.59	-6.88
D x G x S1	4.691	0.601	7.80
D x NC x S1	-0.1449	0.0159	-9.10
D x NT x S1	0.1051	0.0138	7.62
D x W x S1	6.874	1.181	5.82
D x NC x S2	-0.0411	0.0032	-12.80

road width, which has a fairly large and positive coefficient. Clay surfaced roads rut at a slower rate than laterite or quartzite surfaced roads.

In the dry and wet seasons an increase in grade leads to a reduction in the predicted change in rut depth. This is attributed to improved surface and subsurface drainage of sections on grade compared to those on the level. An increase in plasticity index results in a decrease in the predicted change in rut depth, because of the better binding or cohesion of the higher plasticity index material.

As would be expected, the rut in the internal wheelpath develops more slowly than in the external wheelpath, but on grades this effect is changed such that on a 7.1 per cent grade ruts in both wheelpaths develop at the same rate. The downhill lane develops ruts faster than the uphill lane, and this is predicted to be dependent on the percentage of fine material in the surfacing passing the 0.074 mm sieve. This influence on the downhill lane is, however, reduced on curves. It is believed that this phenomenon occurs because vehicles pay more attention to driving in the existing ruts to ensure braking capability in the region devoid of loose material. Outside the wheeltracks the loose material could act as a lubricant.

6.4 RUT DEPTH AFTER BLADING

To develop a model for predicting the rut depth immediately after blading, this rut depth would be required. It was impossible to coordinate measurements on all 48 study sections to coincide with applied maintenance, and rut depth measurements were made as soon as possible after blading, usually within a few days. Consequently, rut depths immediately after blading had to be computed. Using the change of rut depth with time model (Equations 6.1a to 6.1c), the rut depth after blading was computed from the average rut depth and average observation time within each blading period. This procedure gives a more realistic estimate of the rut depth after blading than if only the first measurement had been used. The analysis was performed with rut depth after blading as the dependent variable, and the following independent variables: (1) grade; (2) horizontal alignment; (3) surfacing material characteristics; (4) qualitative surfacing type descriptor; (5) uphill or downhill lane; (6) external or internal wheelpath; (7) average daily number of cars and trucks; and (8) the interaction of wet season with these aforementioned independent variables. In this analysis, those measurements taken during the transition portion of the wet season were removed from the analysis, since by definition, no bladings occur during this time.

The significant variables are shown in the model for the rut depth immediately after blading:

$$\begin{aligned} FRD = {} & 5.46 + 3.80T1 + 4.74T2 + 0.0158\ NT \\ & + S2(0.178G - 587.4/R - 0.118\ PI + 3.00T1 \\ & + 0.0226\ NC - 0.0134\ NT) \end{aligned} \tag{6.2}$$

where

FRD = rut depth after blading in mm;

T1 = surfacing type dummy variable:

T1 = 1, if surfacing is quartzite,

T1 = 0, otherwise;

T2 = surfacing type dummy variable:

T2 = 1, if surfacing is clay,

T2 = 0, otherwise;

NT = average daily truck traffic in both directions;

S2 = wet season dummy variable after first blading in first two months of wet season or after two months in wet season S2 = 1 otherwise, S2 = 0;

G = absolute value of grade in percent;

R = radius of curve in m;

PI = plasticity index, in percent;

NC = average daily car traffic in both directions.

The t-values for the coefficients are given in Table 6.3. This model has an R-squared of 0.24, a standard error of 6.25 and the sample size was 2364. The 95 percent confidence interval for this model is FRD + or - 12.2.

In the dry season (S2 = 0), the coefficients of the surfacing type dummy variables signify different rut depths for the different surfacing types. This is believed to be attributable to dif-