CHAPTER 5 - UNPAVED ROAD GRAVEL LOSS ANALYSIS

5.1 *SCOPE OF THE GRAVEL LOSS STUDIES*

Regravelling is the major maintenance operation on unpaved roads, and it is analogous in importance to overlaying a paved road with asphaltic concrete. It is therefore important that the agency responsible for regravelling know when it should be programmed. The gravel loss studies were aimed at predicting the loss of surfacing material on sections with laterite and quartzite gravel and sections without gravel, *i.e.*, clay. The surfacing material of these latter sections contained more than 35 percent material passing the 0.074 mm sieve. A data summary of the dependent and independent variables studied is given in Table 5.1. These statistics aid in putting the model inference space into perspective. Original data are contained in Working Documents 9, 13, 14, and 15 of this project (Visser and Queiroz, 1979).

5.2 *APPROACH FOR GRAVEL LOSS ANALYSIS*

Gravel loss is defined as the change in gravel thickness over a period of time. On a well compacted subgrade the change in gravel level or gravel height is the change in gravel thickness. Although gravel thickness is not necessarily equivalent to gravel level or gravel height under all conditions, gravel thickness is used in this report as a synonym for gravel level or height. Since gravel loss is a change of gravel thickness over time, it was not necessary to determine an absolute value at some initial point in time as was done for unpaved roughness and rut depth. Gravel loss was evaluated for the interval between regravellings, which initiated a new analysis cycle, or from the time of the first observation until a regravelling occurred.

Three major influences were identified as affecting gravel loss. These are weathering, traffic, and the influence of maintenance in the form of blading. Material properties and road alignment and width then influence the gravel loss generated by each of these influences. The general model is then:

$$\text{gravel loss} = (\text{time})f_1 + (\text{time})(\text{average daily traffic})f_2 + (\text{bladings})f_3$$

TABLE 5.1 - 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 5.1 - 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

where f_1, f_2, and f_3 are linear combinations of material properties and road alignment and width.

The average elevation of a subsection relative to the bench mark was used to evaluate gravel loss. These elevations were obtained at about three monthly intervals, and it was not possible to separate seasonal influences. In the Kenya study (Hodges, Rolt and Jones, 1975) it was shown that no seasonal pattern existed in the data, and this also appeared to be the case for the Brazil data. Furthermore, seasonal influences do not have any practical implications since the agency responsible for regravelling wishes to know its frequency in terms of years, and has little interest in the influences of each particular season.

5.3 *ANALYSIS OF GRAVEL LOSS*

The analysis of gravel loss considered the following independent variables: (1) time in days since observations started or since regravelling; (2) grade; (3) horizontal curvature; (4) liquid limit and (5) plasticity index of surfacing material; (6) the percentage of surfacing material passing the 0.42 mm sieve and (7) the 0.074 mm sieve; (8) qualitative description of the surfacing type, *e.g.*, laterite and quartzite; (9) numbers of vehicles per day of each of cars, buses, pickups, two-axle trucks and other trucks and truck-trailer combinations; (10) road width; and (11) the number of bladings since observations started or since regravelling. Three factor interactions were also investigated, *i.e.*, time and bladings times two factor interactions of the other independent variables.

The GLM procedure of the SAS statistical package (SAS Institute, 1979) was used to determine the significant factors. This procedure permitted evaluation of different combinations of factors, unlike stepwise regression where it is difficult to determine significant effects in cases of high correlation among factors.

Two models containing terms multiplied by the number of bladings were developed within experimental conditions, where the maximum number of bladings was 23. Some organizations, such as the U.S. Forest Service (Lund, 1973), blade a road at very frequent intervals - some times daily - and this gives a value of B far in excess of that used to develop the model. This leads to unrealistically high gravel loss predictions. To overcome this limitation a model containing only interactions with time was investigated. The significant factors are the following:

$$GL = D(-1.58 + 0.366\ G + 0.083\ SV - 0.210\ PI + 0.0132\ NC + 0.0081\ NT + 420.45/R) \quad (5.1)$$

where

GL = gravel thickness loss in mm;
D = time period considered, in hundred days, *i.e.*, days/100;
G = absolute value of grade in percent
SV = percentage of surfacing material passing the 0.074 mm sieve;
PI = plasticity index (PI)
NC = average daily car and pickup traffic, both directions;
NT = average daily truck traffic, both directions;
R = radius of horizontal curvature, in m.

The t-values of each coefficient are given in Table 5.2. The R-squared of this model is 0.60, the sample size 604, and the standard error of the model 11.43. Assuming normality of the residuals, the approximate 95 percent confidence interval is GL + or - 22.8 mm.

Several observations relate to this model.

1. Increasing the grade, the percentage of material passing the 0.074 mm sieve, the average daily car and truck traffic, or decreasing the radius of curvature increases gravel loss.
2. Increasing the plasticity index decreases the gravel loss, *i.e.*, the plasticity index represents the cementing or binding ability of the fine material.
3. Gravel loss associated with the passage of one passenger car is twice that of one truck passage. Care should be taken in attaching too much weight to the vehicle equiv-

TABLE 5.2 - GRAVEL LOSS REGRESSION ANALYSIS (MODEL 5.1)

Parameter	Estimate*	Standard Deviation	t-value
D	1.58	0.96	1.64
D x G	0.366	0.103	3.56
D x SV	0.083	0.016	5.01
D x PI	-0.210	0.054	-3.88
D x NC	0.0132	0.0030	4.40
D x NT	0.0081	0.0027	3.01
D/R	420.45	116.07	3.62

* Negative sign denotes gravel loss.

alency factors, as demonstrated below.

4. Attempts were made to evaluate the effects of each of the different vehicle types, but the relatively small numbers of buses, pickups and trucks other than two-axle resulted in insignificant influences, or these vehicle influences resulted in illogical signs on the coefficients which were incompatible with field experience. Consequently only two vehicle types were used.
5. Surfacing material properties explained the influence of surfacing type sufficiently well such that the qualitative surfacing type descriptors were not found to be significant.

Model (5.1) also contains blading influences although not explicitly defined. When using this model it is assumed that the importance of blading influences decreases as the frequency of blading increases. For example, the effect of a blading every day on gravel loss is not the same as a blading every three months. On the average, it is assumed for Model (5.1) that blading influences are constant irrespective of the number of bladings that occur.

5.4 DISCUSSION OF THE MODELS

Despite of the dangers of developing vehicle equivalency factors, Model (5.1) has a wide applicability and is suggested as the model for general use. The effects of the factors that were found to be significant are in general agreement with field experience. A comparison of gravel loss measurements and the predicted gravel loss for two sections are given in Figures 5.1 and 5.2. Figure 5.1 shows the information for Section 205, which,according to the records, was never bladed in an 18 month period. The predicted gravel loss was centered through the mean date and mean gravel thickness. Section 251, on the other hand, was heavily trafficked, received frequent bladings and is one of the sections on which almost three years of data were collected. The predicted curves were again centered through the mean gravel thickness and mean time for each period between re-gravellings. Both figures demonstrate good concordance between measurements and predictions. In some cases the gravel thickness mea-

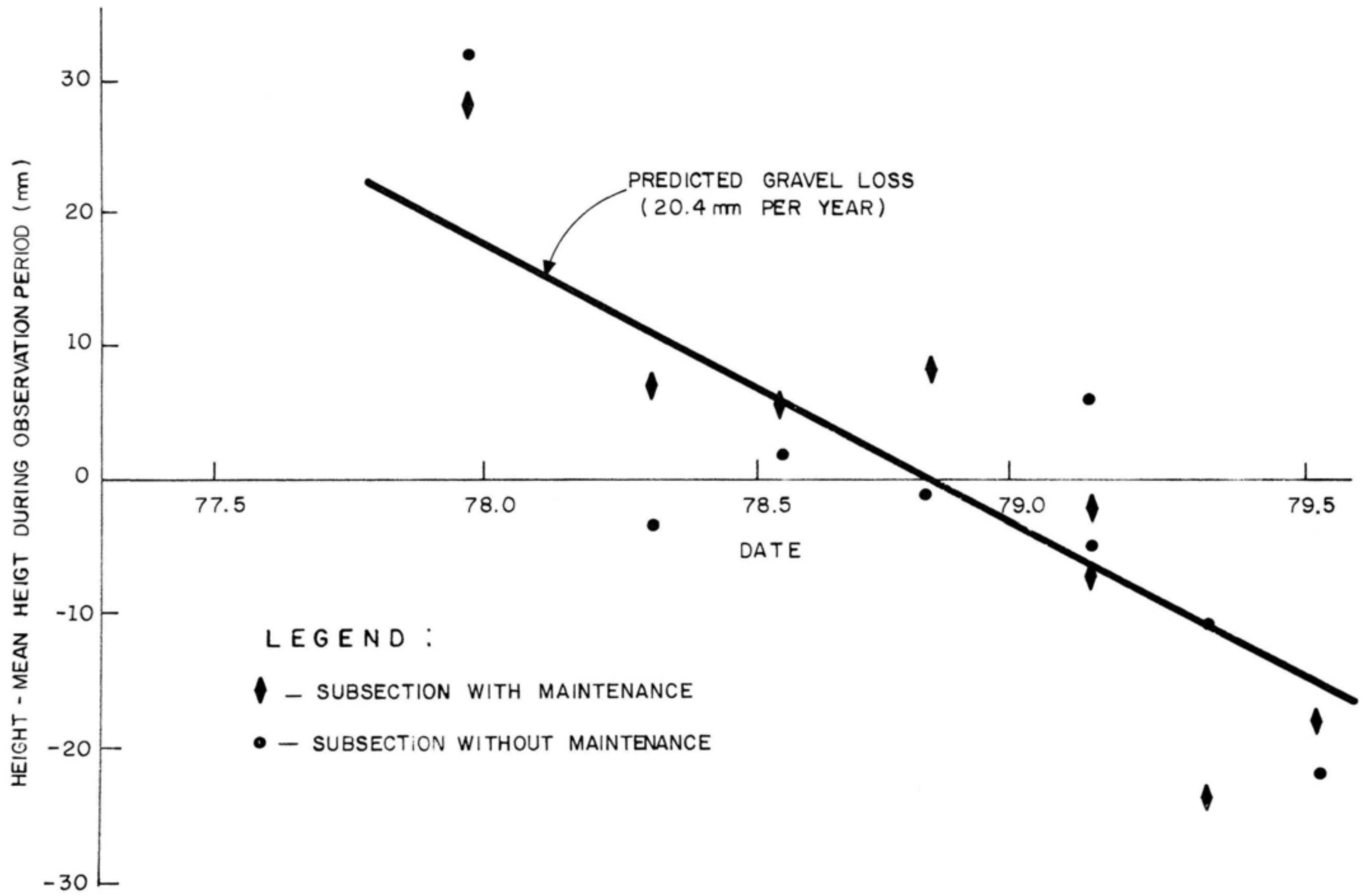

FIGURE 5.1 - PREDICTED AND MEASURED GRAVEL LOSS ON SECTION 205.

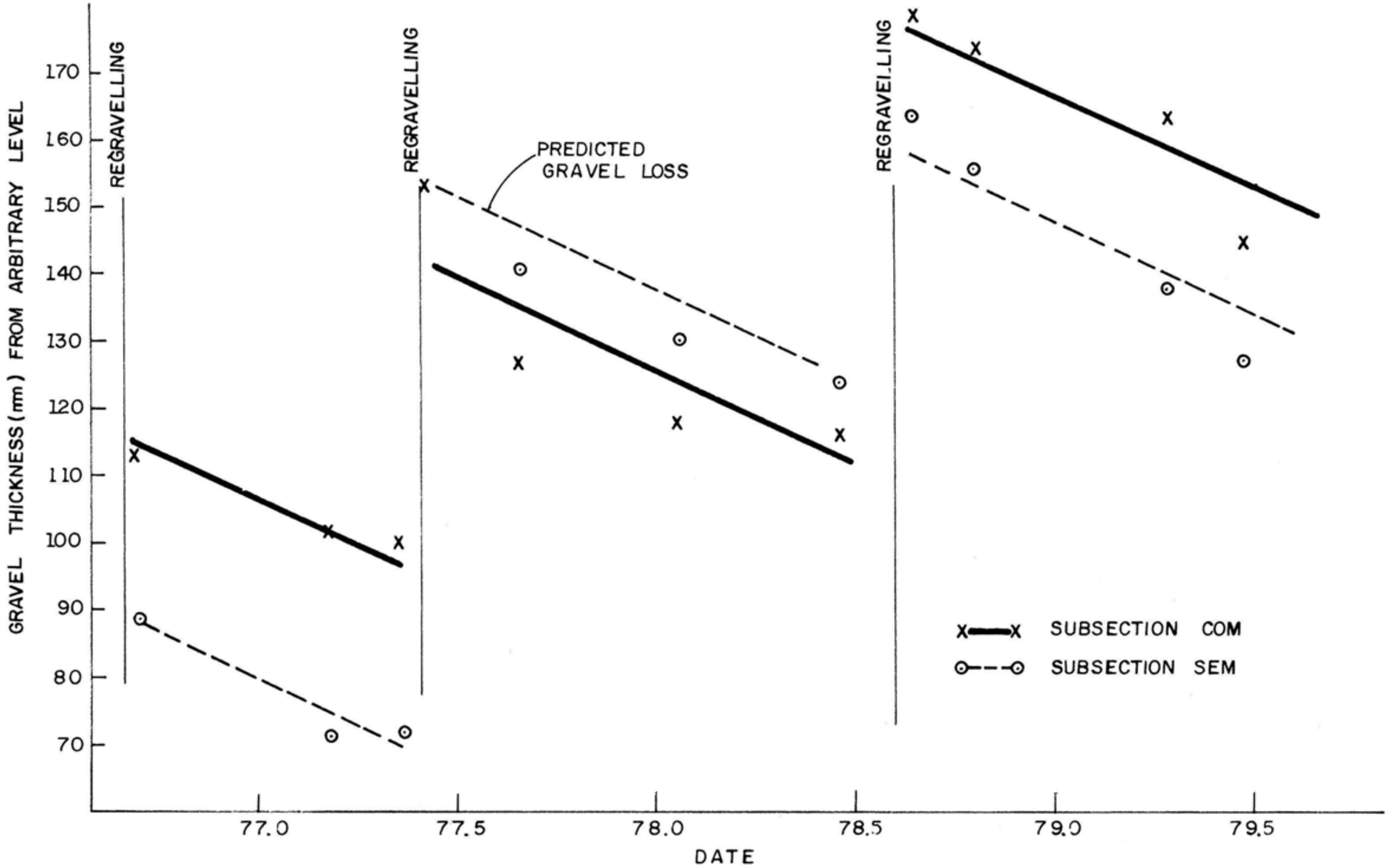

FIGURE 5.2 - PREDICTED AND MEASURED GRAVEL LOSS ON SECTION 251.

sured after regravelling on, for example, Section 251, was much higher than that predicted. This is attributed to the material being relatively uncompacted. In other cases, the material was relatively well-compacted as shown by the predicted and measured gravel thickness, although to the best knowledge only traffic compaction was used in all cases. It could be argued that it would be necessary to predict initial compaction effects, but since this is extremely variable and little information on the degrees of compaction is usually available, this will have little benefit. When calculating gravel quantities, engineers take bulking and compaction effects into account to achieve a final compacted thickness. In repeating this type of study it may be worthwhile to initiate measurements, say, one month after regravelling, to overcome initial compaction effects.

Table 5.3 was generated from Model (5.1) to assist in obtaining some feel for the behavior of the model. Values covering the extremes of the independent variables were selected. This resulted in combinations which normally do not exist in practice, such as a surfacing material containing 10 percent of the material passing the 0.074 mm sieve which has a plasticity index of 30. For this case the model predicts a gravel gain, which is unrealistic. To avoid the prediction of unrealistic values for cases such as these, it is necessary to use a nominal annual gravel loss of, say, 5 mm whenever the gravel loss is less than this value.

An attempt to include cumulative rainfall in the model was unsuccessful since it resulted in a model that predicted contrary to held experience, and also resulted in a change-over of effects within the data range studied.

5.5 *SUMMARY*

Model (5.1) is recommended for general use and comparison of the predictions from this model with data collected in Kenya show good agreement. From a very limited comparison it appears that although the Brazil data was collected in a region of about 1600 mm annual rainfall, the model is valid for predicting gravel loss in low rainfall regions, *e.g.*, below 750 mm per year. An attempt to include rainfall in the Brazil gravel loss prediction model was un-

Grade (%)	Plasticity Index	% Passing the 0.074 mm Sieve	Cars ADT → Truck ADT → Curvature Radius (m) →	Tangent				180			
			Truck ADT	0		400		0		400	
			Cars ADT	15	400	15	400	15	400	15	400
0	0	10		9.5*	28.1	21.3	39.9	18.1	36.6	29.9	48.4
		90		33.8	52.3	45.6	64.1	42.3	60.8	54.1	72.7
	30	10		-13.5	5.1	-1.6	16.9	-4.9	13.6	6.9	25.4
		90		10.1	29.3	22.6	41.1	19.3	37.8	31.1	49.7
8	0	10		20.2	38.8	32.0	50.6	28.7	47.3	40.6	59.1
		90		44.4	63.0	56.3	74.8	53.0	71.5	64.8	83.4
	30	10		-2.8	15.8	9.0	27.6	5.7	24.3	17.6	36.1
		90		21.4	40.0	33.3	51.8	30.0	48.5	41.8	60.4

* OBS: POSITIVE VALUES DENOTE GRAVEL LOSS

TABLE 5.3 - ANNUAL GRAVEL LOSS GENERATED FROM MODEL 5.1.

successful.

Under certain combinations of factors outside the range in which the model was developed, gravel gains or unrealistically low gravel loss can occur. To overcome this problem a minimum annual gravel loss of 5 mm should be used, irrespective of the model predictions. Very short radius curves result in unrealistically high gravel loss predictions, and from a comparison with the Forest Service Study a substitution of a 100 m radius for smaller radius curves in Model (5.1) is recommended.