CHAPTER VI

ROAD DETERIORATION AND ROAD MAINTENANCE

This chapter deals with various aspects of road deterioration, road maintenance, and stage construction as related to the operation of the Road Transport Investment Model. The chief difficulty is studying the above items is the scarcity of information and appropriate data. In Thailand, there are very few studies of road deterioration and there seems to be no stated maintenance policy. Thus, in the present study, there can be no comparison between the road maintenance costs obtained from the model and actual maintenance costs. This chapter will describe how the model estimates road deterioration and road maintenance cost and how the principle of stage construction is employed by the model.

The deterioration relationships were derived from the Kenya field data (HODGES, J.W., ROLT, J., and JONES, T.E., 1975). Whenever the Kenya data were found to be unsatisfactory or incomplete, data from other sources were examined in detail and suitable relationships were derived from those data for use in the model.

Pavement Strength

The pavement strength is expressed as a modified structural number and is used in the model as an index, expressed by Eq. 44

$$SN' = \sum_{i=1}^{n} a_i D_i/2.54 + 3.51 \log_{10} CBR - 0.85(\log_{10} CBR)^2 - 1.43 \qquad (44)$$

where SN' = modified structural number;

a_i = strength coefficient of i-th pavement layer;

D_i = thickness of the i-th pavement layer; cm

CBR = California bearing ratio of the subgrade

The value of strength coefficient for each layer can be obtained from the following equations (Eqs. 45, 46, and 47).

For granular base materials, where $20 \leq CBR \leq 120$:

$$a_2 = [29.14 (CBR) - 0.1977 (CBR)^2 + 0.00045 (CBR)^3] \times 10^{-4} \quad (45)$$

For cement - stabilized base materials, where $0 \leq UCS \leq 14$ MN/m^2

$$a_2 = [750 + 386 (UCS) - 8.83 (UCS)^2] \times 10^{-4} \quad (46)$$

For sub - base material, where $3 \leq CBR \leq 120$:

$$a_3 = 0.01 + 0.065 \log_{10}(CBR) \quad (47)$$

where: a_2 = strength coefficient for base material;

a_3 = strength coefficient for sub - base material;

CBR = California bearing ratio; and

UCS = 7 - day unconfined compressive strength, MN/m^2.

The strength coefficients use in the model for pavement surface must be provided by the model user. Suggested values are given below.

Single surface dressing	0.1
Road mix (low stability)	0.2
Plant mix (high stability)	0.4
Sand asphalt	0.4

The modified structural number (SN') for the study portion of the Saraburi - Lomsak Highway was computed by the model to be 3.5 ; this level of magnitude is associated with a high standard of pavement strength.

Pavement Roughness

The relationships used to evaluate pavement roughness were derived from the Kenya data. The value of the modified structural number of the pavement (SN') provides the means to select the appropriate empirical formula from the following array.

$SN' \leqslant 2.5$	$R = R_o + 3200\ N$	(48)
$SN' = 3.0$	$R = R_o + 483\ N$	(49)
$SN' = 3.5$	$R = R_o + 159\ N$	(50)
$SN' \geqslant 4.0$	$R = R_o + 119\ N$	(51)

where R = roughness, mm/km, measured by a fifth - wheel bump integrator towed at 30 km/h ;

R_o = roughness when the road was new ; and

N = total cumulative traffic loading in millions of equivalent (8200 kg) standard axles.

If the current roughness of the road surface is not known, the model assumes the default option that the initial roughness was 2500 mm/km. The present condition of the road is then calculated from the traffic loading. The relationships are not expected to be valid above a traffic loading of 2.5 - million equivalent standard axles, and the road is considered to have failed when the roughness exceeds 4000 mm/km. Therefore, if no reconstruction or upgrading has been specified by the model user before these levels are reached, the model prints a warning message to indicate which limit has been exceeded. Only if both limits are exceeded does execution terminate.

Rut Depth

Rut depth has been shown to have no measurable effect on vehicle operating costs ; therefore, rut depth relationships for paved roads have not been included in the model.

Cracking

An estimate of pavement cracking is necessary to determine the level of maintenance required by a road. Two aspects of cracking must be predicted: (1) the amount of cracking in the wheel tracks, and (2) the total pavement area where severe local cracking has occurred.

Paved Road Maintenance Requirements

Regular maintenance of paved roads is carried out by patching pot-holes and badly cracked surfaces. The model assumes that patching is regularly carried out each year ; deterioration relationships are not available for roads that are not patched. Periodic maintenance by surface dressing or over-laying may be carried out and dealt with by the model at the discretion of the user. Sealing of cracks and filling of ruts have not been included in the model as maintenance options because, although used occasionally to rectify premature pavement failures, the techniques are not generally used for routine maintenance. Excessive cracking is best dealt with by the application of a surface dressing ; excessive rutting, which is indicative of pavement fatigue, is perhaps best corrected by an overlay.

Maintenance Operations

Maintenance operations are carried out in the model using packages of plant and labour working at certain rates of productivity. However, provision has been made in the model for the user to specify his own maintenance packages with their appropriate productivity values for any given maintenance operation.

If the inbuilt packages are used, the model user must specify the hourly cost of seven types of plant and four different categories of labour. The plant items are : (1) 4,500 - liter self - propelled bitumen distributor ; (2) 0.25 - ton vibrating roller ; (3) grader (3.7 - m blade) ; (4) 10 - ton self - propelled roller ; (5) tractor mower (1.8 m wide) ; (6) water tank (6 m^3) ; and (7) tipper truck (4 m^3). The labour items are: (1) common labourer ; (2) truck driver ; (3) plant operator ; and (4) foreman. The composition and productivities of the various packages are shown in Table 14.

The user must specify the following unit costs : (1) liquid bitumen cost per liter at source ; (2) surface dressing stone cost per cubic meter at source ; (3) base patching material cost per cubic meter delivered at the site; (4) surface patching material cost per cubic meter delivered at the site ; (5) gravel cost per cubic meter at source ; (6) water cost per cubic meter at source ; and (7) diesel fuel cost per liter delivered to maintenance depot. The average transport distances (kilometers) to the site must be specified for the following items : (1) liquid betumen ; (2) gravel ; (3) surface dressing stone ; (4) water ; and (5) labour (assumed to be the average distance from the

Table 14 Details of RTIM Productivity Packages

Operation	Plant				No. of common labourers	No. of foremen	Productivity
Light (surface) patching	0.25-tonne vib. roller	Tipper	-	-	6	1	19 m^2/hr
Heavy (base) patching	0.25-tonne vib. roller	Tipper	-	-	7	1	3 m^3/hr
Shoulder grading	Grader	-	-	-	1	-	7000 m^2/hr
Shoulder mowing	Tractor mower	-	-	-	1	-	5000 m^2/hr
Wet season grading	Grader	-	-	-	1	-	7000 m^2/hr
Dry season grading	Grader	Water truck	Water truck	-	1	-	7000 m^2/hr
Drainage maintenance	Tipper	-	-	-	10	1	10 m^3/hr
Surface dressing	Bitumen distrib.	10-tonne roller	Tipper	Tipper	23	1	1600 m^2/hr
Regravelling	Grader	10-tonne roller	Water truck	-	3	1	350 m^2/hr

maintenance depot to the site). Maintenance plant fuel consumption has been taken into account in the model as shown in Table 15.

Table 15 Maintenance Plant Fuel Consumption

Item of plant	Fuel consumption on open road (liters /km)	Fuel consumption when working on site (liters/ hr)
Bitumen distributor	0.25	12.0
0.25 - ton vib. roller	Transported on tipper	1.0
Grader	1.00	20.0
10-ton roller	1.00	6.0
Tractor mower	0.20	4.0
Water truck	0.30	12.0
Tipper	0.25	10.0

The ratiosof working time to total time used in the model for each item of plant and for labour are shown in Table 16.

Table 16 Ratio of Working Time to Total Time

Item	Bitumen distributor	Vibrating roller	Grader	10 - ton roller	Mower	Water truck	Tipper	Labour
$\frac{\text{Working time}}{\text{Total time}}$	0.8	0.5	0.9	0.8	0.9	0.6	0.8	0.8

The model calculates the job time by :

$$\text{Total time} = \left(\frac{\text{Work content}}{\text{Productivity rate}}\right) \bigg/ \left(\frac{\text{Working time}}{\text{Total time}}\right) \quad (52)$$

The total cost of the maintenance operation is calculated as follows.

Total cost = labour hire + plant hire + fuel to site + fuel on site + materials + haulage. (53)

Patching

The relationships used in the model are shown in the following array, selection of the appropriate expression being made from the modified structural number of the pavement.

$SN' \leq 2.5$	$P = 262\ N_1 + 1190\ N_1^2$	(54)
$SN' = 3.0$	$P = -645 + 1000\ N_1 + 792\ e^{-2(N_1 + 0.32)^2}$	(55)
$SN' = 3.5$	$P = 215\ N_1 - 92(1 - e^{-2.25 N_1})$	(56)
$SN' = 4.0$	$P = 25\ N_1$	(57)
$SN' > 4.0$	$P = 0$	(58)

where P = patching in m^2/km per year for each traffic lane. All areas where cracking exceeds 5 m/m^2 are assumed to be sub-base level;

N_1 = cumulative traffic in millions of equivalent standard axles since the last surface dressing.

Under certain circumstance, the amount of patching predicted by these equations will exceed the total pavement area. As this is unrealistic, an upper limit of 1800 m^2/km has been included in the model.

In the 4th, 8th, and 12th years of analysis of the study highway (being the 1st, 5th, and 9th years of operation of the highway, respectively), the amount of patching called for by the model is shown in Table 17.

Table 17 Maintenance Patching of Saraburi – Lomsak Highway Called for by RTIM : Amount in sq.m/km and Total Cost of Each Section , Baht

Analysis year	Units	Section 1 (0.8 km)	Section 2 (14.1 km)	Section 3 (24.8 km)	Section 4 (26.9 km)	Total (66.6 km)
4	–	none	none	none	none	none
8	sq.m/km	23	163	90	90	–
	Baht	1,100	136,567	133,317	144,605	415,589
12	sq.m/km	480	238	none	none	–
	Baht	28,550	199,937			228,487

Surface Dressing

If the maintenance policy chosen by the model user is that of surface – dressing, the whole width of the carriageway is assumed to be resurfaced with a single seal whenever one of the following limits is exceeded: (1) the mean cracking in the wheel tracks on either side of the carriageway reaches 1.m/m^2; (2) after five years have elapsed since the previous surface dressing; (3) the traffic loading since the previous surface dressing reaches 1.5 – million equivalent axles in either direction. The rate of application of bitumen is assumed to be 1.2 liter/m^2 with stone spread at 14 kg /m^2.

Surface dressing was specified for this analysis to be required when either the cumulative traffic loading reached 1.5×10^6 equivalent standard axle loads or seven years of operation, whichever occurred first. For the Saraburi – Lomsak Highway the amounts of surface dressing for each section are shown in Table 18.

Table 18 Surface Dressing of Saraburi – Lomsak Highway : Area of Treatment, sq.m/km and Total Cost for Each Section, Baht

Analysis year	Units	Section 1 (0.8 km)	Section 2 (14.1 km)	Section 3 (24.8 km)	Section 4 (26.9 km)	Total (66.6 km
7	sq.m/km	21,000[1]	None	None	None	-
	Baht	69,730				69,730
10	sq.m/km	21,000	7,500	7,500	7,500	-
	Baht	69,730	435,429	765,700	830,652	2,101,511

[1] Estimated from total maintenance cost for 7^{th} year.

Overlaying

If the maintenance policy chosen by the model user is that of overlaying, the whole width of the carriageway will be overlaid whenever either of the following limits is exceeded: (1) any roughness value up to 4000 mm/km can be selected by the model user to be the maximum value allowed before an overlay is necessary; (2) the mean cracking in the wheel tracks on either side of the carriageway reaches 3 m/m^2. (This latter condition will not arise if the road is surface dressed regularly.)

The thickness of bituminous carpet which is used to overlay the existing pavement depends on the design traffic loading of the pavement and the structural condition of the pavement before overlaying. In the model, the thickness of overlay must be specified by the model user. After the addition of an overlay a new value of the modified structural number is calculated as follows:

$$SN'_f = 0.9\ SN'_i + (a_q)\ (D_q)/2.54 \quad (59)$$

where SN'_i = initial modified structural number ;

SN'_f = final modified structural number ;

a_q = strength coefficient of the overlay material ;

D_q = thickness of the overlay, cm.

In the present analysis of the Saraburi - Lomsak Highway, the condition requiring an overlay did not occur during the table analysis period of 12 years.

Shoulder Maintenance

The following four shoulder maintenance techniques are used in the model.

(1) Unpaved shoulders of roads with a paved surface more than 6.5 meters wide.

Maintenance consists of a single grading each year and grass mowing at regular intervals. The area to be graded is assumed to be 4,800 m^2/km, ie,a strip 2.4 meters wide on each side of the carriageway. The number of mowings required each year is assumed to be one for every 500 mm of annual rainfall, and the complete width of the shoulder is mown.

(2) Unpaved shoulders of roads having a paved surface less than 6.5 meters wide.

The frequency of grading is increased by 50 percent for each meter that the paved running surface is less than 6.5 meters wide. It is assumed that these gradings are scheduled for the wet season and thus only a motor grader is required.

(3) Surfaced shoulders of roads with a bitumen running surface more than 6.5 meters wide.

The maintenance consists of patching and surface dressing. The patching of the shoulders is assumed to be 10 percent of that required for the running surface. The shoulders are surface dressed at half the frequency of the running surface. If no surface dressing is specified for the running surface, none will be carried out on the shoulders.

(4) Surfaced shoulders of roads with a bitumen running surface less than 6.5 meters wide.

The maintenance is identical with that specified in (3), above, except that the amount of patching is increased by 50 percent for every meter that the paved running surface is less than 6.5 meters wide.

For the present analysis of the Saraburi - Lomsak Highway, the first criterion stated above applies : the bitumin running surface is more than 6.5 meters wide and there are unpaved shoulders. It should be noted that shoulder maintenance occurs in every year ; the unit cost found by the model for the study highway is 215 Baht per route kilometer.

Drainage Maintenance

The amount of sediment to be removed each year is estimated from Eq. (60).

$$SD = 6+0.003(1000+RL)(TE)(SSF) \qquad (60)$$

where SD = sediment, m^3/km ;

RL = annual rainfall, mm;

TF = terrain adjustment factor;

= 1 for mountainous terrain;

= 2 for rolling terrain;

= 3 for flat terrain;

SSF = side slope factor.

$$= \frac{1}{\text{cut slope}} + \frac{1}{\text{fill slope}} + 0.5 \qquad (61)$$

The value of TF can be found from the average of the reciprocals of the terrain run-off coefficients at the minor river crossings. If there are no minor river crossings the terrain is assumed to be rolling.

Drainage maintenance is carried out during each year of the life of the project. The cost of this maintenance item is based on the cost of removing the sediment.

Drainage maintenance for the Saraburi - Lomsak Highway was found by the model to be as shown in Table 19. The quantities and cost do not vary from year to year.

Table 19 Quantity and Cost of Drainage Maintenance for Saraburi - Lomsak Highway for a Typical Year

	Section 1 (0.8 km)	Section 2 (14.1 km)	Section 3 (24.8 km)	Section 4 (26.9 km)	Total (66.6 km)
Quantity, cu.m/km	87	87	41	59	-
Cost, Baht	745	12,887	10,677	16,620	40,929

Stage Construction

Four types of reconstruction and upgrading may be used in the model. These are:

(1) Overlaying: An additional pavement layer is placed on top of the existing pavement structure. Overlaying may also be carried out as a maintenance operation for paved roads.

(2) Pavement reconstruction: One or more pavement and shoulder layers are placed on top of the existing pavement structure.

(3) Road widening: A new road cross section is designed and additional pavement and shoulders are added as required.

(4) Realignment: The road is widened and the pavement reconstructed on a new vertical alignment. The new alignment may be specified by the user or generated by the model.

The procedures outlined above may be used to upgrade from an earth road to a gravel road by adding a gravel layer, or to upgrade earth or gravel roads into paved roads by adding extra layers. Reconstruction or upgrading will take place when either of two parameters reach a threshold value set by the model user. These parameters are: (1) traffic volume, expressed in passenger car units; (2) roughness, expressed in mm/km.

None of the four stage construction procedures described were applied in the present analysis of the Saraburi - Lomsak Highway.