CHAPTER VII

RESULTS AND DISCUSSION OF RESULTS

This chapter is concerned with the results of applying the RTIM to the Saraburi - Lomsak Highway. Comparison was made of the construction costs determined by the model to the actual construction contract. Sensitivity of some items of construction cost (eg, earthworks) were studied with respect to their principal variables (eg, side slopes). Comparison was made of the vertical alignment generated by the model with the engineer's design, with especial attention being paid to contruction cost as a figure of merit. The results of the vehicle operating costs comprise a comparison between the costs generated by the model and road user costs in Thailand obtain from T.P.O'S ULLIVAN & PARTNERS (1973). Review was made of the basic maintenance policy incorporated in the model with respect to the fraction of the total annual cost of transportation, the components of which are maintenance cost of the highway, amortization of the highway investment, and vehicle operating cost. Economic analysis and simple sensitivity analysis of the model to traffic growth and capital discount rates was carried out over appropriate ranges of these variables.

Construction Costs

Construction costs were available from the Final Report (DE LEUW, CATHER, 1970) that the consulting engineer presented to the Department of

Highways. However, the costs shown in the final report were not always in the form required by the model ; supplementary information was obtained from the consultants and the Department of Highways. All costs are in Thai Baht and details of the costing are given in Appendix D Table D 1. Table 20 gives a breakdown of the construction costs estimated by the model and compares them with those of the actual contract.[1] Table 21 shows the subdivision by percent of total cost of the construction costs estimated by the model and those of the actual contract.

As can be seen, the construction costs estimated by the model are in good general agreement with those of the contract. Earthworks costs are lower and several factors probably account for this ; a discussion of the estimates of earthworks costs produced by the model appears latter in this Chapter.

The site clearance cost was underestimated by the model, probably due to the cleared area being widened on the inside of horizontal curves to improve driver visibility. The model has not taken acount of this extra clearing.

Where the road location passed over unstable soils, an extra pavement layer of improved subgrade was incorporated into the design. The thickness of this layer varied, depending on the subgrade material. Where sections of

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[1] The reader is reminded that the present study dealt with only the southern portion of the Saraburi - Lomsak Highway, a segment of 66.6 route kilometers.

Table 20 Construction Costs for the Saraburi - Lomsak Highway (Thai Baht)

Item	Costs from the model					Contract amount	% of diff.
	Section 1 (0.8 km)	Section 2 (14.1 km)	Section 3 (24.8 km)	Section 4 (26.9 km)	Total (66.6 km)		
Site clearance	27,048	473,760	833,280	903,840	2,237,928	2,348,080	- 4.6
Earthworks	278,764	6,183,926	19,795,900	10,150,338	36,408,928	41,182,878	-11.6
Pavement	1,683,569	7,887,892	13,873,740	15,048,532	38,493,733	37,196,730	+ 3.5
Shoulders	156,021	1,821,861	3,204,408	3,475,749	8,658,039	8,386,141	+ 3.2
Culverts	-	471,438	526,242	476,948	1,474,628	1,734,620	-15.0
				Sub - total	87,273,256	90,848,449	- 3.9
Bridges	394,056	1,240,496	6,084,843	6,250,735	13,970,130	13,970,130	-
Miscellaneous	709,457	594,565	1,008,200	1,094,925	3,407,147	3,407,147	-
Total	3,248,915	18,673,938	45,326,613	37,401,067	104,650,533	108,225,726	- 3.3

Table 21 Percentage Subdivision of Construction Costs for the Saraburi - Lomsak Highway

Item	From Model, %	From Contract, %
Site clearance	2.1	2.2
Earthworks	34.8	38.1
Pavement	36.8	34.4
Shoulders	8.3	7.7
Culverts	1.4	1.6
Bridges	13.3	12.9
Miscellaneous	3.3	3.1
Total	100.0	100.0

the road location pass over different soils, estimates were made of the average thickness of the added improved subgrade layer; it is probably this averaging that led to the small error in the pavement cost.

The small error in shoulder costs likely occurred because the model assumes that the shoulders are of constant thickness whereas, in the design, they are tapered.

The largest error which occurred is that for culverts. This cost is made up of two parts: crossflow drains at regular intervals and culverts for minor river crossings. Errors appear for several reasons. The model uses Talbot's formula for estimating the flow at the river crossings; the method used in the engineer's design is another method which is described in Chapter IV and is likely to have produced a different value of stream flow. In the design contract, minor river are carried under the roadway in concrete pipes; the model assumes that these are corrugated metal pipes. The headwalls assumed by the model are not of the same design as those used in the contract. Finally, the lengthsof culverts depend on the heights of embankments, and the model only takes an average value of the length of these pipes.

In the present study, the cut slopes and fill slopes were varied to determine the degree of sensitivity of earthwork volume to various slopes. Earthwork volumes were found to be extremely sensitive to the cut and fill slopes. The results of varying these slopes are shown in Table 22. The terrain through which the study section of the Saraburi - Lomsak Highway is situated varies considerably. Section 1 is very flat. Section 2 lies in

Table 22 Sensitivity of Earthworks Volume to Side Slopes

Item	Section 1 (0.8 km)	Section 2 (14.1 km)	Section 3 (24.8km)	Section 4 (26.9km)
Excavation, m^3 (Cut slope)[1]	10,112 (1 : 2.0)	2,634 (1 : 2.0)	365,034 (1 : 0.5)	136,387 (1 : 2.0)
	11,336 (1 : 2.5)	3,116 (1 : 2.5)	420,709 (1 : 0.8)	169,692 (1 : 2.5)
Exbankment, m^3 (Fill Slope)[1]	37 (1 : 2.0)	319,839 (1 : 2.0)	433,184 (1 : 2.0)	314,414 (1 : 2.0)
	40 (1 : 2.5)	348,990 (1 : 2.5)	541,480 (1 : 2.5)	342,159 (1 : 2.5)

[1] Cut and fill slopes are shown as rise : run

slightly rolling ground. Section 3 is in very rugged terrain with deep rock cuts and high embankments. Section 4 is in moderately rolling to flat terrain.

Average Side Slope for Rock Cuts

The design for study Section 3 of the Saraburi - Lomsak Highway, portions of which are in deep rock cuts, called for benched cuts which are shown in somewhat simplified form in Fig. 15. As RTIM can accept only a single value for cut (or embankment) slopes, it was necessary to synthesize a single - valued side slope for the benched section. This was obtained by an analysis of the cross - sectional areas. Because of the peculiarities of the design section, several depths of cut were studied with the results as follows.

H, met	Equivalent Single - value Side Slope (rise : run)
6	1 : 1
8	1 : 0.67
10	1 : 0.92
12	1 : 0.85
14	1 :0.80
16	1 :0.75

From the foregoing results, selection of 1 :0.8 was made for the equivalent single - value side slope for study Section 3.

From Table 22 it can be seen that changing the cut slope from 1 :0.5 to 1 :0.8 for the deep rock cuts occurring in Section 3 changed the volume of excavation by about 15 percent. For the other route sections, a change in the cut slopes from 1 :2.0 to 1 :2.5 for earth cuts changed the volume of excavation by 12 to 24 percent, depending on the terrain in the three sections.

Changing the fill slopes from 1 :2.0 to 1 :2.5 changed the embankment volumes by 8 to 9 percent, also depending on the terrain in Sections 1, 2, and 4. As shown in Table 21,earthwork cost was about 38 percent of the total construction cost for this project. Due to this high proportion, substantial errors can appear in the total construction costs if the cut and fill slopes are not worked with care. The model assumes constant side slopes for embankments and excavations. In the engineer's design, the fill slopes depend on the height of embankment and the stability of soil ; the cut slopes are benched to increase the side slope stability and improve the drainage of deep cuts.

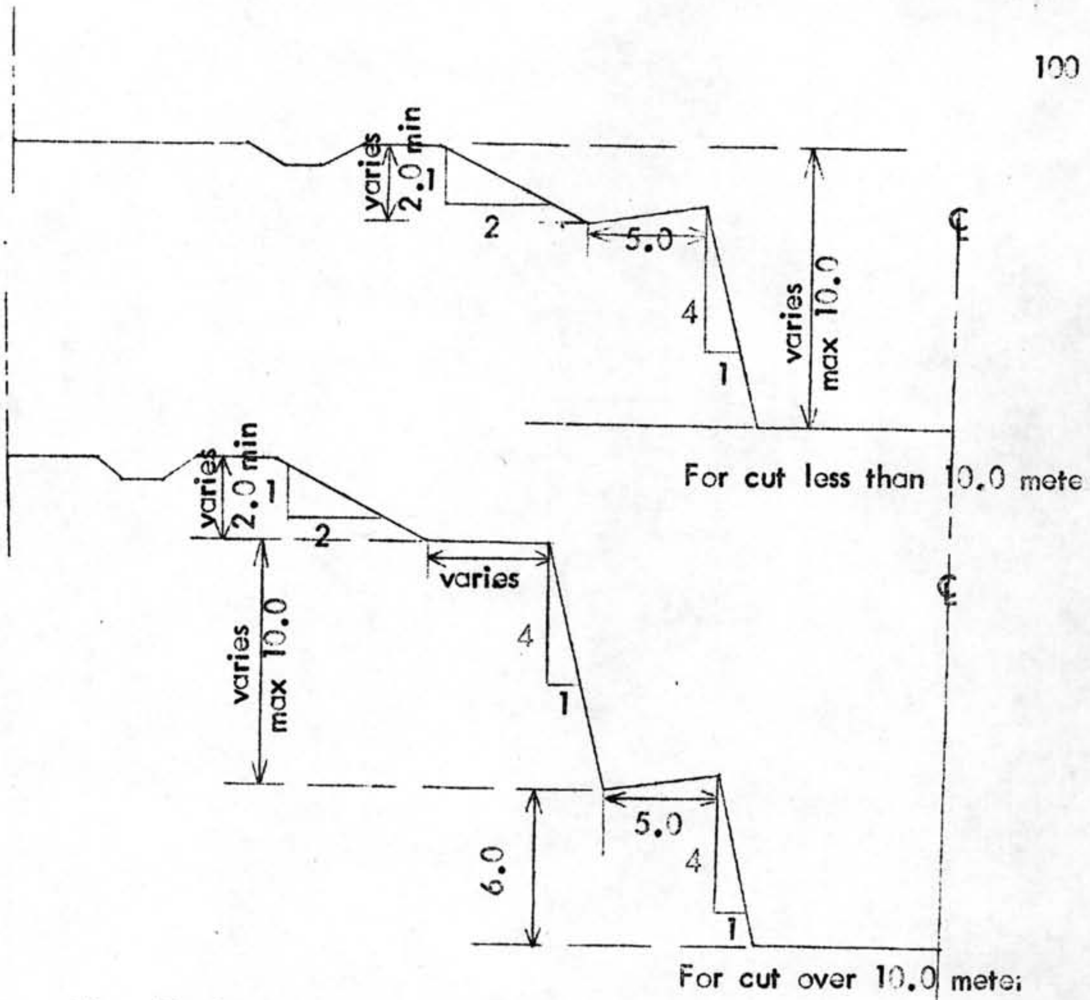
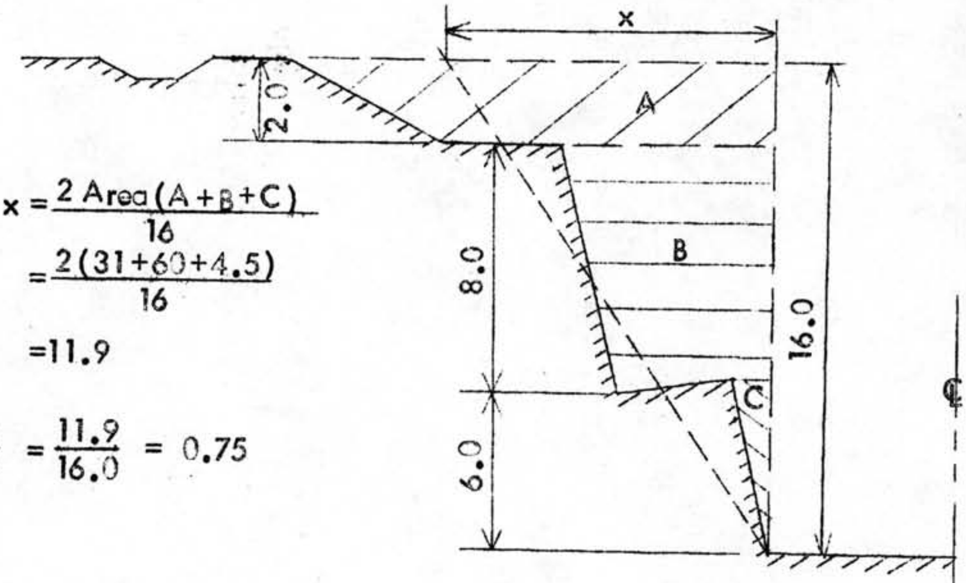


Fig. 15 Criteria for Design Rock Cut Sections



$$x = \frac{2\,\text{Area}\,(A+B+C)}{16} = \frac{2(31+60+4.5)}{16} = 11.9$$

$$\frac{\text{run}}{\text{rise}} = \frac{11.9}{16.0} = 0.75$$

Fig. 16 Example of Determination of Equivalent Single-Value Side Slope for Rock Cuts in Study Section 3

Furthermore, Section 1 and Section 2 designs required the removal of much unstable soil prior to constructing embankments. Such factors in the designs represent substantial extra costs for excavation and embankments, this led to the model estimating lower earthwork quantities and costs than those which occurred during the actual construction of the highway.

Fig 17 shows the cumulative volumes of earthwork for different side slopes for the whole study section.

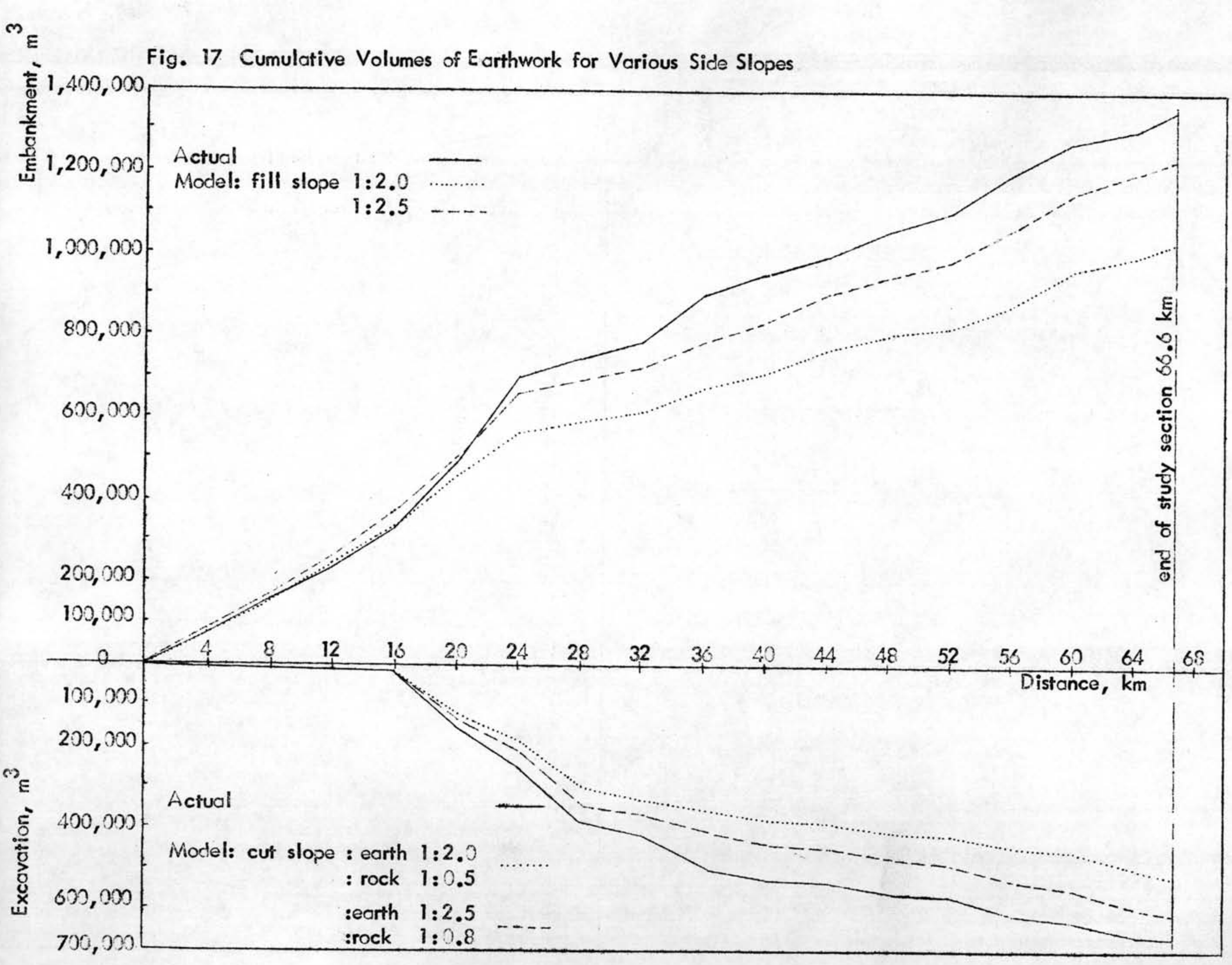
In general practice, earthwork costs are calculated from the mass haul diagram. However, in Thailand only the unit cost of excavation and the unit cost of embankment are earthwork contract cost items ; no separate costing is made of haul. Working from average end areas of the roadway cross sections, the model generates a mass - haul diagram and calculates the quantities of haul in units of cubic - meter - kilometer, and total borrow and spoil volumes in cubic meters. The mass - haul diagram is an effective tool for estimating earthwork costs and planning earthmoving operations.

In the present study, the following unit costs were used in the model :

excavation	=	24.5	Baht per cu meter ;
compaction	=	10.0	Baht per cu meter :
haul	=	1.5	Baht per cu - meter - km ;
borrow	=	15.0	Baht per cu meter ;
spoil	=	3.0	Baht per cu meter.

The model in the first trial calculated the earthwork volumes by using the mass - haul analysis. In the second trial, only the unit cost of excavation (24.50 Baht per cubic meter) and the unit cost of embankment (17.50

Fig. 17 Cumulative Volumes of Earthwork for Various Side Slopes



Baht per cubic meter) were input to the model. The other items were put in as zeros. The results of these calculations and a comparison of them are shown in Table 23. The values shown in the lower part of Table 23 were used in the analysis of costs shown in Table 20 because these costs are based on the quantities of cut and fill which formed the engineer's estimate for payment of the actual construction contract.

Table 23 Costs of Earthwork in Baht

Using the Mass Haul Diagram, Baht				
Item	Section 1 (0.8 km)	Section 2 (14.1 km)	Section 3 (24.8 km)	Section 3 (26.9 km)
Excavation	278,064	76,443	10,320,000	4,162,555
Haul	0	2,075	2,317,224	297,579
Compaction	402	3,489,968	5,414,797	3,421,585
Borrow	0	5,188,236	1,811,560	2,586,994
Spoil	33,886	0	0	0
Total	312,352	8,756,740	19,863,581	10,468,713
Using only Unit Cost for Cut and Fill, Baht				
Item	Section 1 (0.8 km)	Section 2 (14.1 km)	Section 3 (24.8 km)	Section 4 (26.9 km)
Excavation	278,064	76,443	10,320,000	4,162,555
Embankment	700	6,107,483	9,475,900	5,987,783
Total	278,764	6,183,926	19,795,900	10,150,338
Difference compared to above	12 %	42 %	0.4 %	3 %

The costs of earthwork for Section 3 were about the same irrespective of the form of unit costing ; the same similarity was found for Section 4. For section 1, a substantial valume of spoil occurred ; this appears in Table 23 as a significant cost. For Section 2 the cost of borrow is a substantial part of the total cost. The use of only the unit costs of excavation and embankment to calculate the earthwork cost provides at best a rough approximation, because the total earthwork cost depends not only on excavation and embankment quatities but also on haul, borrow, compaction and spoil which are variable fractions of the in - place costs of embankments and excavations .

Comments on Construction Cost Analysis

Referring to Table 20 it can be seen that for all construction items except culverts and earthworks, it was possible to calibrate the model to within 5 percent. This required judicious selection of surrogates for the actual design details which, because of their complexity, simply could not be used directly as input parameters. The overall precision of the calibration for the four segments of the Saraburi - Lomsak Highway that were studied is represeuted by the 3 percent difference between the model construction cost and the contract construction cost.

Vertical Alignment Generated by the Model

When a vertical alignment has not been input to the model, a suitable alignment will be generated automatically by RTIM using a method based on program Venus. This method uses a smoothing technique to produce a vertical alignment consisting of parabolic curves and connecting tangents. The alignment will approximate the ground and will satisfy the specified geometric design standards, but will not necessarily balance nor minimize cut and fill quantities.

In the present study, a comparison of the vertical alignment generated by the model with the engineer's design is shown in Fig.18. Data for the elevation of road plotted in Fig. 18 are presented in Tables 24 and 25.

The model approximately balances the areas of cut and fill along the center - line profile of the road but as seen in Table 26 the calculated volume of excavation is more than twice the fill volume. In the engineer's design, which strove to balance earthwork volumes, the excavation and fill volumes are close to each other (difference = 5 %). Care must be taken when the model is programmed to generate the vertical alignment, because it uses only the center - line ground data which may lead to badly unbalanced earthwork volumes.

Vehicle Operating Costs

Basic data for vehicle operating costs were obtained from T. P. O' SULLIVAN & PARTNERS (1973). All costs are in Thai Baht and are given in Appendix D. The primary analysis was carried out for a 5 percent growth rate and a 12 percent discount rate. Subsequently variations in these two rates were introduced, as described later in this Chapter.

Fig. 18 Typical Ground Longitudinal Section and Vertical Alignments

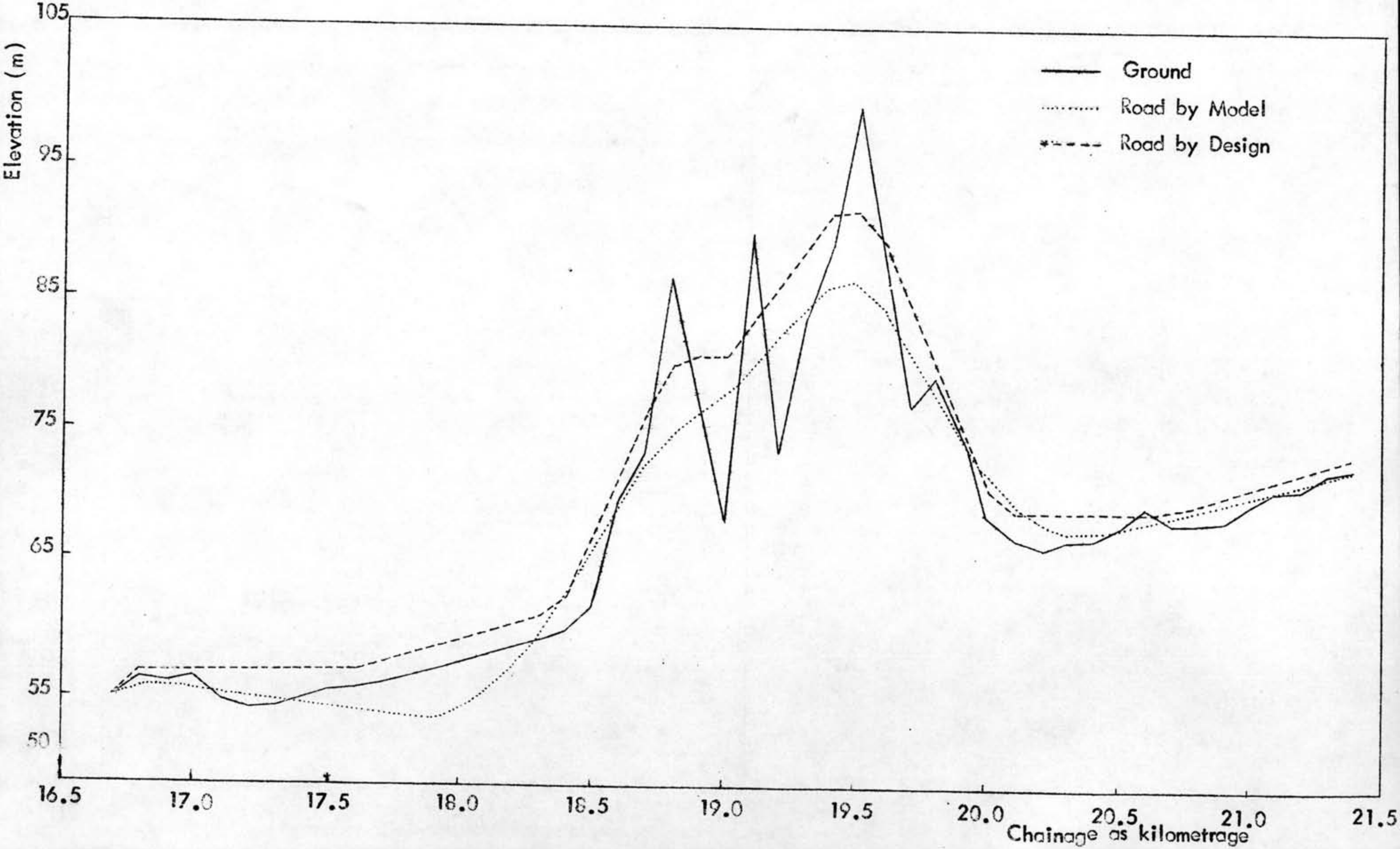


Table 24 Vertical Alignment Generated by RTIM (Portion of Study Section 3)

Intersection point		Curve	Radius	Rate of change of	%
Chainage	Elev.	length	(sag curves –)	% gradient	Gradient
16700.0	54.400				
					1.4320
16750.0	55.116	96.59	8081	.01237495	
					.2368
16846.6	55.345	96.59	20302	.00492562	
					-.2390
18121.9	52.297	612.28	-16144	.00619395	
					3.5534
18734.2	74.054	315.84	14764	.00677332	
					1.4141
19050.0	78.520	100.00	-11753	.00850768	
					2.2649
19150.0	80.785	69.18	-9861	.01013985	
					2.9663
19219.2	82.837	69.18	7044	.01419739	
					1.9842
19494.1	88.291	274.89	5119	.01953544	
					-3.3859
20129.1	66.791	520.94	-14167	.00705827	
					.2910
20650.0	68.307	520.94	-196542	.00050880	
					.5561
21270.7	71.759	312.46	-312455	.00032005	
					.6561
21583.2	73.809	312.46	113370	.00088207	
					.3805
22531.9	77.419	555.60	-62064	.00161120	
					1.2757
23087.5	84.507	550.67	48942	.00204322	
					.1505
23638.2	85.336	550.67	-30629	.00326472	
					1.9483
24300.0	98.230	295.42	36040	.00277472	

Table 25 Vertical Alignment From Engineer's Design (Portion of Study Section 3)

Intersection point		Curve length	Radius (sag curve -)	Rate of change of % gradient	% Gradient
Chainage	Elev.				
16700.0	54.400				
					2.2000
16800.0	56.600	110.00	5000	.02000000	
					.0000
17600.0	56.600	60.00	-9999	.01000000	
					.6000
18400.0	61.400	150.00	-3408	.02933333	
					5.0000
18800.0	81.400	200.00	3636	.02750000	
					-.5000
19000.0	80.400	100.00	-2923	.03420000	
					2.9200
19500.0	95.000	300.00	3811	.02624127	
					-4.9524
20025.0	69.000	200.00	-4037	.02476190	
					.0000
20670.0	69.000	60.00	-9999	.01000000	
					.6000
22315.0	78.870	60.00	7500	.01333333	
					-.2000
22500.0	78.500	60.00	-3999	.02500000	
					1.3000
23000.0	85.000	70.00	5385	.01857143	
					.0000
23390.0	85.000	60.00	-5999	.01666667	
					1.0000
23700.0	88.100	60.00	-7499	.01333333	

Table 26 Comparison of Earthwork Quantities: RTIM-VS. Engineer's Design Section 3[1]

	Engineer's Design	RTIM	RTIM - Design	$\frac{\text{RTIM - Design}}{\text{Design}} \times 100$
Volume of excavation, m^3	399,456	608,292	208,836	+52%
Volume of fill, m^3	418,194	267,654	-150,540	-36%

[1] 13.4 km, from Chainage 16700 to 30100.

For paved roads, the speed depends on the type of vehicle, horizontal curvature, rise and fall, and altitude. Fuel consumption depends on type of vehicle, speed, rise and fall, and horsepower; for heavy vehicles, the gross vehicle weight becomes a factor. Since none of the geometric factors change throughout the life of the road, it is presumed that all speeds and fuel consumption will remain constant. Speeds, fuel consumption, and fuel costs for each class of vehicle and for each section of the highway are given in Table 27.

The relationships used in the model to predict vehicle speeds and fuel consumption rates were developed under substantially free-flow conditions where the only constraints on speed were the physical characteristics of the road and the vehicle. It may be presumed that derived rates of fuel consumption for each class of vehicle will not be valid when traffic interaction takes place. The predicted vehicle speeds seem high. In this analysis, the model predicted average speeds of cars of about 100 kph. A comparison of the fuel consumption costs are shown in Table 28 for Section 3 in this study.

The remainder of the vehicle operating costs depend on surface roughness and vehicle age. Surface roughness increases through the life of the road, until surface dressing has been done. The age of the typical vehicle increases or decreases, depending upon the relationships between the initial vehicle-age spectrum, the vehicle usage rate, and the vehicle growth rate. This means that the age of the typical vehicle will sometimes increase and sometimes decrease, and therefore the vehicle operating costs will sometimes

Table 27 Average Vehicle Speeds and Fuel Consumption from the Model

	Vehicle Type[1]	Average Speed, km/h		Fuel Consumption, (liters/1000 km		Average fuel cost per km Thai Baht
		Direction		Direction		
		Northbound	Southbound	Northbound	Southbound	
Section 1	1	102	102	127	130	0.1547
Rise = 0 m/km	2	87	86	200	205	0.2425
Fall = 1 m/km	3	73	72	274	281	0.2497
(Northbound)	4	68	67	211	219	0.1936
Curvature = 0.02 °/km	5	68	67	164[2]	257[2]	0.1895
	6	68	67	231[2]	358[2]	0.2651
Section 2	1	101	102	132[3]	126[3]	0.1545
Rise = 3 m/km	2	85	86	207	197	0.2426
Fall = 0 m/km	3	71	72	286	271	0.2506
(Northbound)	4	66	68	224	208	0.1947
Curvature = 2.38 °/km	5	66	68	262	246	0.2285
	6	66	68	364	347	0.3199
Section 3	1	98	98	129	128	0.1538
Rise = 6 m/km	2	83	83	204	203	0.2440
Fall = 6 m/km	3	69	69	286	284	0.2564
(Northbound)	4	64	65	225	223	0.2012
Curvature = 11.88 °/km	5	64	65	166[2]	257[2]	0.1904
	6	64	65	237[2]	361[2]	0.2691
Section 4	1	100	100	129	129	0.1543
Rise = 4 m/km	2	84	84	203	203	0.2439
Fall = 4 m/km	3	70	70	283	283	0.2545
(Northbound)	4	66	66	221	221	0.1991
Curvature = 6.32 °/km	5	66	66	162[2]	256[2]	0.1882
	6	66	66	234[2]	360[2]	0.2670

[1]Vehicle Type
1 is car and taxi
2 is light truck
3 is light bus
4 is heavy bus
5 is 2-axle truck
6 is 3-axle truck

[2]Southbound heavy vehicles, type 5 and 6 are more heavily loaded in southbound direction.

[3]All traffic on Study Section 2 is southbound, see footnote on page 29.

Table 28 Comparison of Fuel Consumption Costs Predicted by the Model with the T.P. O'Sullivan Study[1]

Vehicle type	Average fuel cost, Baht per kilometer[2]	
	Model	T.P.O'Sullivan
Cars and taxis	0.1538	0.142[3]
Light trucks	0.2440	0.140
Light buses	0.2564[4]	0.118[5]
Heavy buses	0.2012[4]	0.197
2-axle trucks	0.1904	0.231
3-axle trucks	0.2691	0.231

[1] T.P. O'SULLIVAN & PARTNERS (1973)

[2] Section 3

[3] Estimated by extrapolation

[4] Logically, light buses should display a lower fuel cost per kilometer than heavy buses. The results shown here stem from an inadvertent bad choice of formulas for fuel cost for these two classes of vehicle

[5] This very low fuel cost per kilometer arises from the low cost of diesel fuel used by this class of vehicle in the T.P.O'Sullivan study

increase and sometimes decrease through the analysis period.

The unit costs of oil, spare parts, maintenance labour, tyres depreciation, interest, crew time, passenger time, and overhead (per vehicle kilometer) are given in Table 29 for the first year of the analysis and in Table 30 for the last (ninth) year. The changes in vehicle operating costs over the analysis period of this road are shown in Table 31. Table 32 shows the vehicle operating costs obtained T.P. O'SULLIVAN & PARTNERS (1973), and Table 33 shows a comparison of the total vehicle operating costs predicted by the model with those from the T.P. O'Sullivan study.

Table 29 Vehicle Operating Costs (Except Fuel) During First Year of Traffic

(Baht per Vehicle Kilometer, Not Discounted)

Vehicle Type	Oil	Spare parts	Maintenance labour	Tyres	Depreciation	Interest	Crew time	Overhead
1	0.0085	0.0234	0.0091	0.0420	0.3820	0.2067	0	0.0825
2	0.0128	0.0304	0.0126	0.0660	0.2573	0.1392	0.3600	0.2806
3	0.0284	0.0053	0.0071	0.2420	0.2084	0.1063	0.4286	0.3206
4	0.0284	0.8816	0.2503	0.7398	0.5545	0.2829	0.7857	0.9311
5	0.0284	0.4501	0.2503	0.6699	0.2832	0.1444	0.4714	0.6220
6	0.0284	0.5188	0.2503	1.8563	0.3263	0.1665	0.4714	0.9718

Table 30 Vehicle Operating Costs (Except Fuel) During Ninth Year of Traffic

(Baht per Vehicle Kilometer, Not Discounted)

Vehicle Type	Oil	Spare parts	Maintenance labour	Tyres	Depreciation	Interest	Crew time	Overhead
1	0.0085	0.0488	0.0180	0.0446	0.3938	0.2067	0	0.0874
2	0.0128	0.0635	0.0250	0.0700	0.2652	0.1392	0.3600	0.2949
3	0.0284	0.0105	0.0138	0.2545	0.2384	0.1063	0.4286	0.3342
4	0.0284	0.8771	0.2459	0.7781	0.6306	0.2829	0.7857	0.9575
5	0.0284	0.4478	0.2459	0.7046	0.3220	0.1444	0.4714	0.6387
6	0.0284	0.5161	0.2459	1.9524	0.3711	0.1665	0.4714	1.0052

Table 31 Change in Vehicle Operating Costs, Including Fuel Cost

(Baht per Vehicle Kilometer, Not Discounted)

Vehicle Type	First Year	Ninth Year
Cars and taxis	0.9080	0.9617
Light trucks	1.4029	1.4747
Light buses	1.6031	1.6711
Heavy buses	4.6556	4.7873
2 - axle trucks	3.1102	3.1936
3 - axle trucks	4.8590	5.0262

Table 32 Vehicle Operating Costs (except fuel) Obtained from T.P. O' Sullivan[1] Study (Baht per Vehicle Kilometer, Not Discounted)

Vehicle Type	Oil	Spare parts	Maintenance labour	Tyres	Depreciation	Interest	Crew time	Overhead
1	0.006	0.075	0.057	0.062	0.372	0.233	-	-
2	0.008	0.083	0.068	0.057	0.204	0.097	0.094	-
3	0.009	0.081	0.061	0.044	0.214	0.091	0.094	-
4	0.016	0.256	0.131	0.170	0.605	0.264	0.156	0.045
5	0.016	0.136	0.131	0.284	0.318	0.140	0.094	0.065
6	0.016	0.136	0.131	0.284	0.318	0.140	0.094	0.065

[1]The T.P.O'Sullivan tablesare entered with average speed; these were obtained from the model-generated average speeds shown in Table 27.

Table 33 Comparison of Total Vehicle Operating Cost Predicted by the Model with T.P.O'Sullivan Study[1]

Vehicle type	Total Vehicle Operating Cost	
	Model	T.P.O'Sullivan
Cars and taxis	0.9080	0.930
Light trucks	1.4029	0.657
Light buses	1.6031	0.618
Heavy buses	4.6556	1.840
2 - axle trucks	3.1102	1.321
3 - axle trucks	4.8590	1.321

[1] T.P.O'SULLIVAN & PARTNERS (1973)

As will be subsequently shown in this chapter, total vehicle operating costs are about 85 percent of the total highway transportation cost, highway costs acount for the major portion of the remaining 15 percent. Therefore, vehicle operating costs are the key factor in an analysis of highway transportation costs.

It is not an easy matter to determine motor vehicle running costs because they are affected by many factors and vary over wide ranges. The main factors that affect motor vehicle running cost may be grouped as follows. A detailed listing of the important components is given in Appendix B.

(a) The highway

(b) The vehicle

(c) The operator

(d) The weather and topography

For economy studies in highway design it is required that these groups of factors be studied so the effect of the highway on the running cost of the vehicles may be determined. There are wide ranges of variation of the three principal factors : highway, vehicle, and operator. Yet, it is necessary to provide the analyst with good and reliable motor vehicle performanace and cost information.

Most of work on road user costs in Thailand was based on a study by DE WEILLE (1966) for the World Bank. T.P.O'SULLIVAN & PARTNERS (1973) studied road user costs in Thailand and attempted not only to use data relevant to Thailand but also to develop technical relationships where there was reason to question those used in the De Weille study.. Therefore, the T.P.O'Sullivan study can be used as a reasonable basis for road user costs in Thailand.

In spite of using the base data for vehicle operating cost from the T.P.O'Sullivan study, the estimates of vehicle operating cost produced by the model are not the same as those derived by T.P.O'SULLIVAN & PARTNERS (1973). This is likely attributable to vehicle operating costs being affected by different conditions and assumptions. For example, fuel consumption is affected by vehicle weight, tyres, body size and design, engine design, power transmission to the driving wheels, and other lesser factors. It is noted that the typical vehicle used by the model is not the same as used in the T.P.O'Sullivan study.

It may be concluded that the basic assumptions and conditions used by the model for estimating vehicle operating costs are not identical to those applicable in Thailand because there proved to be considerable discrepancy between the two sets of results, as was shown in Table 33. If the model could be altered to reflect the assumptions and conditions that are appropriate to Thailand, more effective estimates of total vehicle operating costs would doubtless occur.

Vehicle operating costs for the four study sections of the Saraburi - Lomsak Highway, for three traffic growth rates, are shown in Appendix Tables C1 through C3.

Road Maintenance Costs

Plant hire rates, labour rates, and materials costs were obtained from the Thai Department of Highways. The maintenance crews were assumed to be similar to those incorporated in the model programme. Details of these costings are given in Chapter VI . The maintenance cost of each section is shown in Table 34 and Appendix Tables C1 through C3. Because the traffic volumes vary from section to section, surface dressing would not be carried out at the same time ; this variation is shown in Table 34. For example in Section 3 (24.8 km), the maintenance operations carried out each year would be shoulder mowing, shoulder grading, and drainage maintenance. The total annual cost of these items is 16,810 Baht (678 Baht per km). After 4 year of service of the road, light surface patching and heavy base patching would be carried out during , and accounted for at the end of, the fifth year of service ; the annual cost of this work rises from 103,000 Baht*(4,150 Baht per km) in

* Including cost of shoulder mowing and grading, and drainage maintenance.

the fifth year to 150,000 Baht*(6,050 Baht per km) in the sixth year. Surface dressing would be carried out after 6 years of service of the road, this would costs nearly 1,000,000 Baht (40,320 Baht per km). After surface dressing has been carried out, the model assumes that the section is like a new road and the maintenence tasks and costs are the same as in the first year.

*See footnote page 116.

Table 34 Annual Maintenance Costs for 5 percent Traffic Growth from RTIM (12 percent Discount Rate)

Analysis year	Maintenance Cost				
	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	979	15,134	16,810	21,645	54,568
5	9,050	15,134	16,810	21,645	62,639
6	13,912	59,068	16,810	21,645	111,435
7	91,260[1]	133,916	16,810	21,645	263,631
8	979	139,854	102,883	115,006	358,721
9	14,224	146,088	150,255	166,389	476,956
10	93,397	631,607[2]	999,274[2]	1,087,342[2]	2,811,620
11	1522	15,134	16,810	21,645	55,111
12	18,303	31,574	16,810	21,645	88,332

[1] Surface dressing required at this time because cumulative traffic loading has exceeded 1.5×10^6 equivalent standard axles.

[2] Surface dressing required because 7 years was specified for this study as the maximum duration to first surface dressing treatment. Surface dressing operation specified for the seventh year of sevice and cost accounted for at end of seventh year, but traffic assumed not to benefit from this improvement until the beginning of the eighth year of service.

In Thailand, the maintenance and repair of highways are usually performed by Highway Department employees using Department - owned equipment. However, some of the larger and less frequently occurring maintenance operations are performed under contracts awarded by competitive bidding.

Despite many years of record keeping of Highway Department operations, there is a paucity of data pertaining to maintenance expenses of a sort that would serve the requirements of a highway economic study. Whilst many factors affect the total expense of maintaining highways, it is difficult to record maintenance expenses directly against the several features of design and traffic which affect those maintenance expenses. The differences in maintenance expense associated with pavement widths, shoulder widths, vertical grades, horizontal alignment, cut and embankment slopes, and types of construction materials are difficult to measure under the normal processes of maintaining highways. Again, the effects of traffic volume and traffic composition on the expense of maintaining highways are not known closely enough. Weather, soil conditions, and time are factors having pronounced effects on highway maintenance expense. For economic studies, however, the desired specific highway maintenance expenses are not available. The parameters of highway maintenance inherent in RTIM, which were derived from the several TRRL studies in Kenya, were accepted for the present research as better data were not available from sources in Thailand.

Finally, a comparison can be made between the actual maintenance expense for the southern portion of the Saraburi - Lomsak Highway with that produced by the model. Records of the Thai Highway Department (Maintenance Division) show the expenditure for routine maintenance for the southern end of the study highway average 13,760 Baht/km for the sixth year of service (this is the ninth analysis year). The average maintenance cost for 66.6 km. as obtained from the model for the ninth analysis year averages 7,160 Baht/km. Whilst there is a substantial difference, with the RTIM value being about half the THD expenditure, it will subsequently be seen that the annual maintenance cost is insignificant compared to the annual vehicle operating on the same segments.

Economic Analysis

The analysis has been carried out for a nominal life of 9 years. Construction would take 3 years with35 percent of the cost being spent in the first year, 49 percent in the second, and 16 percent in the third year. For this analysis, all classes of traffic were assumed to grow at 5 percent per annum . The total cost of the individual sections of as road produced by RTIM are shown in Table 35 and the cash flows through the 12 years of the analysis are shown in Table 36. Details of the discounted maintenance costs and vehicle operating costs, for three traffic growth rates, are shown in Appendix Tables C4 through C6.

During this period, the road maintenance costs are very small, representing less than 1 percent of the net present value (NPV) of the total transportation cost. Vehicle operating costs are more than 5 times the cost of initial construction, on the basis of net present value.

Table 35 RTIM Costs for Saraburi - Lomsak Highway Study Sections

(66.6 km), Baht

Section	Construction	Maintenance	Vehicle Operation
1 (0.8km)	2,654,395	94,819	18,195,083
2 (14.1km)	15,256,791	433,688	168,115,386
3 (24.8km)	37,032,289	462,963	148,995,580
4 (26.9km)	30,557,040	515,119	161,525,292
Total (66.6km)	85,500,515	1,506,589	496,831,341

Table 36 Cash Flow[1] for Saraburi - Lomsak Highway Study Sections (66.6 km), Baht

Analysis Year	Construction Cost	Discounted at 12%	Maintenance Cost	Discounted at 12%	Vehicle Operation	Discounted at 12%
1	36,627,687	32,703,292				
2	51,278,761	40,879,114				
3	16,744,085	11,918,109				
4			54,568	34,678	108,716,173	68,455,576
5			62,639	35,543	114,077,639	64,730,717
6			111,435	56,456	120,955,020	61,279,579
7			263,631	119,253	128,161,089	57,973,569
8			358,721	144,881	135,548,039	54,745,581
9			476,956	171,995	143,222,986	51,647,646
10			2,811,620	905,266	151,280,075	48,708,136
11			55,111	15,843	159,811,025	45,941,852
12			88,332	22,673	168,885,430	43,348,685
Total, NPV		85,500,510		1,506,589		496,831,341

[1]For 5 percent per annum traffic growth

Simple sensitivity analysis of the model were carried out with these data by varying the traffic growth and discount rates. Traffic growth rates of 5, 10, and 15 percent -- and discount rates of 10, 12 and , 15 percent -- were studied.

Construction costs, of course, were not affected by changes in traffic growth, but the change with discount rate is shown in Table 37. The cost of road maintenance increases with increasing traffic and the effect is shown in Table 38. A change in traffic of 5 percent cause a change of about 17 percent (when traffic growth increases from 5 to 10 percent), and 24 percent (when traffic growth increases from 10 to 15 percent) in the maintenance cost. This percentage of change in the maintenance cost also depend on the traffic volume of the base year. If the traffic volume of base year is high the maintenance cost will also high and increase rapidly when the traffic growth is increased, In the present study, traffic volume of the base year is very high, therefore, the change in maintenance cost very high when increasing traffic growth rate.

Table 37 Construction Costs for Different Discount Rates

Percent of Total	Analysis Year	Construction Cost	Discounted at 10 %	Discounted at 12 %	Discounted at 15 %
35 %	1	36,627,687	33,297,897	32,703,292	31,850,163
49%	2	51,278,761	42,379,141	40,879,114	38,774,110
16%	3	16,744,085	12,580,079	11,918,109	11,009,508
Total	-	-	88,257,117	85,500,515	81,633,781

Table 38 Sensitivity of Road Maintenance Costs to Traffic Growth and Discount Rate

Discount rate	Traffic growth rate, precent per annum		
	5 %	10 %	15 %
10 %	1,775,435	2,075,719	2,568,215
12 %	1,506,589	1,762,316	2,171,600
15 %	1,185,820	1,388,344	1,700,985

Table 39 Sensitivity of Vehicle Operating Cost to Traffic Growth and Discount Rate

Discount rate	Traffic growth rate, percent per annum		
	5 %	10 %	15 %
10 %	570,572,292	679,123,460	814,400,840
12 %	496,831,330	588,154,039	701,583,160
15 %	407,110,630	478,152,154	565,950,060

Table 40 Sensitivity of Total Cost to Traffic Growth and Discount Rate

Discount rate	Traffic growth rate, percent per annum		
	5 %	10 %	15 %
10 %	660,604,844	769,456,296	905,226,172
12 %	583,838,445	675,416,870	789,255,275
15 %	489,930,231	561,174,279	649,284,826

Vehicle operating costs for the different traffic growth and discount rates are shown in Table 39. A traffic growth rate increase from 5 to 10 percent causes an increase of about 18 percent in vehicle operating cost, and a traffic growth rate increase from 10 to 15 percent causes an increase of about 19 percent in the vehicle operating cost. In the actual case, the vehicle operating cost may increase more than these amounts when the vehicle flow increases beyond the critical value of hourly flow. This would cause reductions in vehicle speeds due to traffic interaction and thus increase vehicle operating cost. However, the model is not valid when traffic interaction takes place.

The variations of total cost (construction plus maintenance plus vehicle operation) with discount rate and traffic growth are shown in Table 40 and Fig. 19. A traffic growth rate increase from 5 to 10 percent causes an increase of about 16 percent in total cost, and a traffic growth rate increase from 10 to 15 percent cause an increase of about 17 percent in total cost. An increase in the discount rate from 10 to 12 percent causes a decrease of about 12 percent in total cost, and a discount rate increase from 12 to 15 percent causes a decrease of about 16 percent in total cost.

The discount rate and traffic forecast are probably the most difficult things to predict in a feasibility study, especially in times of high inflation and of steeply rising fuel costs. It is interesting to note that a 5 percent traffic growth, with all costs discounted at 10 percent, gives a total transportation cost similar to a 15 percent traffic growth with all costs discounted at 15 percent.

Fig. 19 Sensitivity of Total Transportation Cost to Traffic Growth and Discount Rates

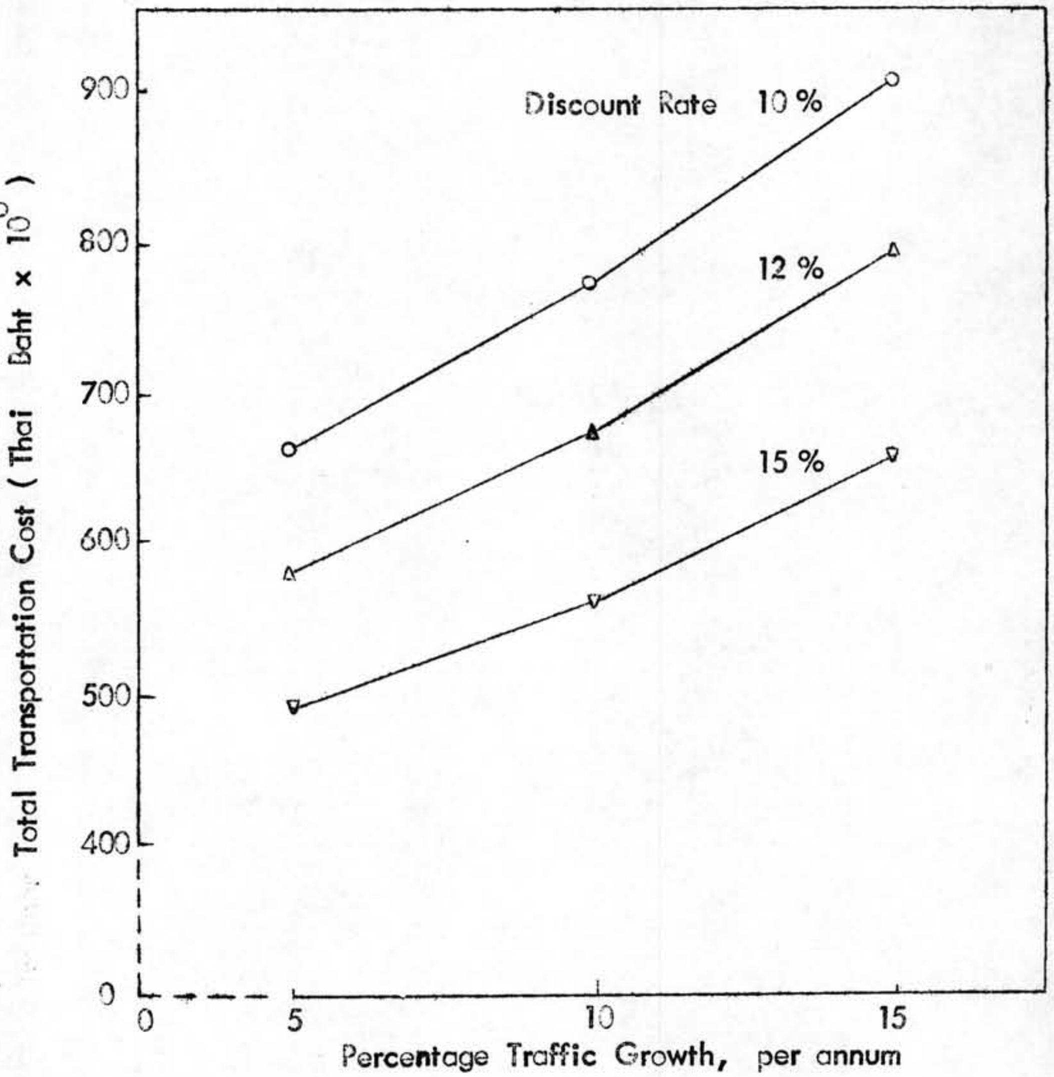
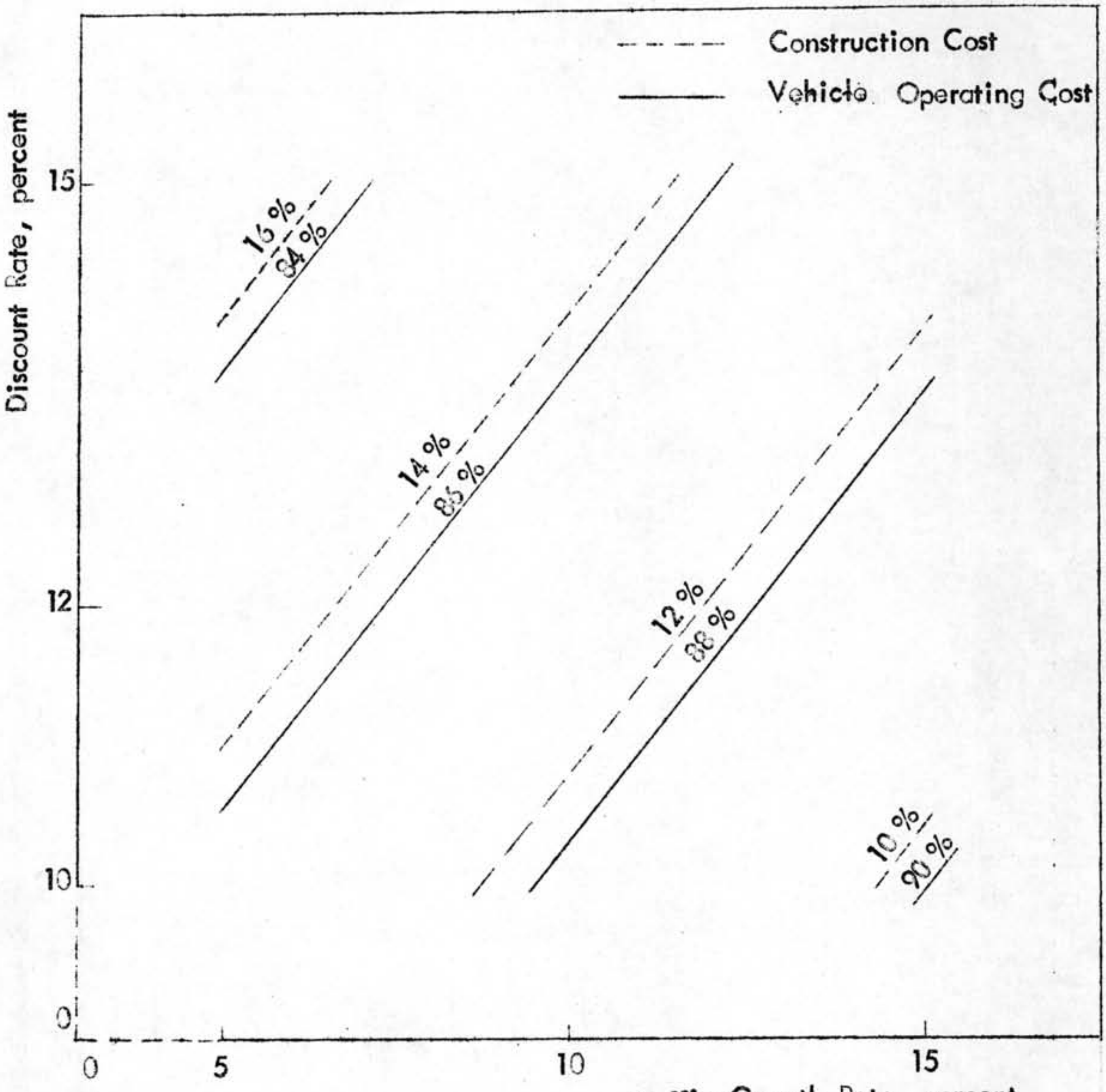


Table 41 and Fig.20 show the sensitivity of the composition of the total transportation cost to traffic growth and discount rates in percentage. The percentage of construction cost of the total transportation cost is lowest for the lowest discount rate (10 percent) combined with the highest traffic growth rate (15 percent); under these conditions, the discounted construction cost cost amounts to only 9.8 percent of the total transportation cost. When the discount rate is highest (15 percent) and the traffic growth rate is lowest (5 percent) the discounted construction cost amounts to 16.7 percent of the total transportation cost. It can be seen that when the traffic growth rate

Table 41 Sensitivity of Composition of Total Cost to Traffic Growth and Discount Rates in Percentage

Discount rate	Composition	Traffic growth, percent per annum		
		5 %	10 %	15 %
10 %	Construction	13.4	11.5	9.8
	Maintenance	0.27	0.27	0.28
	Veh. Operating	86.4	88.3	90.0
12 %	Construction	14.6	12.7	10.8
	Maintenance	0.26	0.26	0.28
	Veh. Operating	85.1	87.1	88.9
15 %	Construction	16.7	14.6	12.6
	Maintenance	0.24	0.25	0.26
	Veh. Operating	83.1	85.2	87.2

Fig. 20 Composition in Percentage of Total Transportation Cost



Note: Road maintenance cost = 0.24 to 0.28%

is high the total transportation cost is also high , because the vehicle operating cost is high, but the construction cost is constant, therefore the percentage of construction cost will be smaller.

The percentage of the total transportation cost attributed to highway maintenance is almost constant and equal to about 0.26 percent of the total transportation cost, which is very small.

The percentage of the total transportation cost attributed to vehicle operation is lowest when the discount rate is highest (15 percent) and the traffic growth rate is lowest (5 percent). Thus the vehicle operating cost varies between 83.1 percent and 90.0 percent of the total transportation cost. The sensitivity of vehicle operating costs is in the apposite sense to that of the construction cost fraction of total transportation cost.

The apportionment of the total transportation cost developed by the model seems reasonable. An analysis by WINFREY (1969) led to the following conclusion :

"Vehicle operating costs as a whole are about 88 percent of the highway transportation cost ; the highway cost accounts for the remaining 12 percent. Therefore, vehicle operating costs are the key factor in the analysis of highway transportation costs."