Chapter IV

RESULTS AND DISCUSSION OF RESULTS

This chapter describes the results from application of the RTIM Model to the Ban Map Pu-Ban Khai Feeder Road. Comparisons of details have been made for construction costs, vehicle operating costs and maintenance costs between the output of the Model and the values estimated by VALLENTINE, LAURIE & DAVIES (1976). Road deterioration in terms of roughness, which effects several parameters of the Model, has been discussed. Time cost output has also been compared with the available data from T.P.O'SULLIVAN (1973). Finally, the components of the total transportation cost of the study road have been shown both as non-discounted costs and as costs discounted to their present worth in 1975. Also, percentage splits of the total cost of transportation into amortized construction costs, vehicle operating costs, and time costs have been shown and comparison was made with those found by SINTHUSARN (1976).

Construction Costs

Detailed construction costs of Section I and Section II as calculated by the Model, and summarized costs of the two sections representing the construction costs of Ban Map Pu-Ban Khai Feeder Road, are shown in Table 16. Table 17 compares the con-

Table 16 Construction Costs Calculated by the Model, Baht

Item	Section I		Section II		Section I&II	
	Quantity m^3	Cost ฿	Quantity m^3	Cost ฿	Quantity m^3	Cost ฿
Excavation	80,475	1,450,166	209,337	3,772,253	289,812	5,222,419
Embankment	123,852	6,269,383	121,034	6,126,750	244,886	12,396,133
Earthwork cost		7,719,549		9,899,003		17,618,552
Site clearance cost	22.40 Ha	122,170	38.61 Ha	210,579	61.01 Ha	332,749
Shoulder cost	29,133	2,598,664	29,744	2,653,214	58,877	5,251,878
Imp. subgrade	7,280	368,513	0	0	7,280	368,513
Subbase	9,230	823,316	0	0	9,230	823,316
Base course	22,490	5,035,511	38,313	8,578,280	60,803	13,613,791
PDSD	3,250	3,439,280	5,569	5,893,074	8,819	9,332,354
Pavement cost		9,666,620		14,471,354		24,137,974
Drainage cost		3,060,849		8,228,072		11,288,921
Miscellaneous costs		2,940,680		5,415,052		8,355,732
Overhead and supervision costs		2,871,938		4,496,500		7,368,438
Total construction cost		28,980,470		45,373,774		74,354,244

Table 17 Comparison of Construction Costs of Ban Map Pu-Ban Khai Feeder Road, Baht

Item	By the Model	By Linear Interpolation of VL&D Estimates	Percent Diff.
Earthworks	17,618,552	19,766,324	-10.9
Site clearance	332,749	334,383	- 0.5
Pavement and shoulders	29,389,852	25,510,240	+15.2
Drainage	11,288,921	11,288,921	-
Miscellaneous	8,355,732	8,355,732	-
Design and supervision	7,368,438	7,178,116	+ 2.6
Total	74,354,244	72,433,716	+ 2.6

struction costs of those calculated by the Model with those obtained by the use of linear interpolation of the VL&D estimates as described in Chapter III. Two problems arose from the application of the Model to the Ban Map Pu-Ban Khai Feeder Road. The first problem was to put the miscellaneous cost data and drainage cost data in terms of currency; these resulted in the figures shown in Table 16. The constraints of the Model required that only one pavement type be used in each computer run, but there were several pavement types used in the VL&D designs for Section I and Section II, so the second problem arose. Equivalent values for the thickness of each pavement layer were calculated as input data to make the pavement quantities estimated by the Model to be equal to those estimated in the VL&D calculations. The result was that the pavement and shoulder cost from the Model was 15.2 percent overestimated. The chief reason for the difference is that the thickness of each pavement layer specified in the input data was the thickness after compaction, whereas the Model calculated the quantities using a compaction factor of 0.8 (from the default option of its program) as a denominator. Thus, the quantities obtained would increase 25 percent. If only one unit cost of material were used, the cost of the pavement would accordingly increase by 25 percent. As there were different kinds of pavement layers, and each had its own unit cost as input data, the excess pavement and shoulder costs could deviate in the range from zero to +25 percent. It is evident that VALLENTINE, LAURIE & DAVIES (1976) estimated the pavement quantities without the use of a compaction factor. If in the present study the pavement thickness had been decreased to overcome the presence of the compaction factor, the strength of the pavement, in term of thickness (which was a factor controlling the deterioration of the road), would decrease resulting in a shorter life of the road.

Equivalent widths of clearing for Section I and Section II were 14.0 m and 13.0 m, respectively, the resulting cost, combined for the two sections, showed little difference due to the rounded values of the input data. VALLENTINE, LAURIE & DAVIES (1976) did not specify clearing over the full right-of-way because of the anticipation of severe problems with erosion in the silty-sandy soils of the route, and of the desire to perform only the necessary construction work. The amount of clearing and grubbing was calculated by a computer programme using cross-sections at 100-m intervals, so the present study had to employ equivalent values based on the total cost for the route of this items.

Earthwork costs calculated by the Model would come out different to the VL&D values because of the use of ground data input to the Model instead of using values estimated from linear interpolation of the total earthwork cost for the whole route.

Nevertheless, the total construction cost calculated by the Model was quite close to the prorata estimate by VL&D; there was only 2.6 percent difference. The results obtained for construction costs were in good agreement with the research done by SINTHUSARN (1976).

Road Deterioration

The deterioration relationships incorporated into the Model were derived from Kenya field data, or from data of other sources when the Kenya data were unsatisfactory or incomplete. The Model represented the deterioration rate in terms of roughness which was expressed in mm/km measured with a fifth-wheel bump-integrator towed at 30 kph. This roughness is a function of the pavement strength and the total cumulative traffic loading in millions of equivalent (8,200 kg) standard axles. The mean initial roughness a new paved road of surface-dressed type, which was used in the present study, was taken as 2,500 mm/km. During the simulation of the life of the road, roughness would increase with the increase in number of cumulative standard axles travelling along the road. The Model considered that the paved road would fail when the roughness exceeded 4,000 mm/km, and the relationships used were valid below a cumulative loading of 2.5-million equivalent standard axles. The Model required that upgrading be done if road deterioration reached its limit, otherwise the program would terminate. In order to make sure that the life of the study road would not end within the analysis period, upgrading as a maintenance operation was specified. The present study used an asphaltic concrete overlay (0.05-m. thick) as a means of upgrading the deteriorated surface. The initial roughness for this type of pavement was taken as 1,500 mm/km. Details of road deterioration for Section I and Section II are shown in Table 18. In Section I, roughness reached its limit of 4,000 mm/km in the 14^{th} year. At that time overlaying took place and thence the condition of the upgraded road was used; ie, restarting the analysis with an initial roughness of 1,500 mm/km and ignoring the cumulative standard axles which had previously passed along the road before upgrading. Certainly, this resulted in additional maintenance cost and would have an effect on the vehicle opera-

Table 18 Road Deterioration of Section I and Section II

Year	Standard Axles		Cumulative Millions of Standard Axles at End of Year		Roughness mm/km	
	Outward	Inward	Outward	Inward	Mid Year	End of Year
	Section I					
3	38,452	38,452	0.04	0.04	2,547	2,595
4	41,229	41,229	0.08	0.08	2,645	2,696
5	43,776	43,776	0.12	0.12	2,750	2,803
6	46,553	46,553	0.17	0.17	2,861	2,918
7	49,100	49,100	0.22	0.22	2,978	3,039
8	52,395	52,395	0.27	0.27	3,103	3,167
9	55,865	55,865	0.33	0.33	3,236	3,305
10	59,217	59,217	0.39	0.39	3,377	3,450
11	62,570	62,570	0.45	0.45	3,527	3,604
12	65,922	65,922	0.52	0.52	3,685	3,766
13	69,274	69,274	0.58	0.58	3,851	3,936
14	73,202	73,202	0.66	0.66	4,026	4,116
15	77,240	77,240	0.08	0.08	1,522	1,544
16	81,485	81,485	0.16	0.16	1,568	1,591
17	85,641	85,641	0.24	0.24	1,616	1,640
	Section II					
3	27,882	27,882	0.03	0.03	2,519	2,539
4	29,839	29,839	0.06	0.06	2,559	2,580
5	31,796	31,796	0.09	0.09	2,602	2,624
6	33,871	33,871	0.12	0.12	2,647	2,670
7	35,828	35,828	0.16	0.16	2,695	2,720
8	38,421	38,421	0.20	0.20	2,747	2,773
9	40,954	40,954	0.24	0.24	2,801	2,830
10	43,480	43,480	0.28	0.28	2,860	2,890
11	45,902	45,902	0.33	0.33	2,921	2,953
12	48,435	48,435	0.38	0.38	2,987	3,020
13	50,961	50,961	0.43	0.43	3,055	3,091
14	53,833	53,833	0.48	0.48	3,128	3,165
15	56,934	56,934	0.54	0.54	3,204	3,244
16	59,807	59,807	0.60	0.60	3,285	3,326
17	63,026	63,026	0.66	0.66	3,370	3,413

ting cost, as will be described next. In Section II, the usable life of the road continued until the end of the analysis period and upgrading was not necessary. Table 18 also shows that, because of the periodic surface dressing used as a maintenance operation in the Model, the road did not deteriorate seriously. This effect is discussed in the section on maintenance.

Vehicle Speed

The relationships used in the Model for calculating the speed for each type of vehicles are entirely dependent on road characteristics. For a paved road, vehicle speed is a function of altitude, rise and fall of road, horizontal curvature, and road width[1]. For an unpaved road, the effect on altitude was neglected by the Model, but additional factors on the moisture content of the surface material and the rut depth (another index indicating the deterioration of an unpaved road) were included. The Model calculated vehicle speed and fuel consumption for each type of vehicle in each direction as shown in Table 19. For the two study sections in the present research, roadway widths were

[1]Vehicle speeds are expected to decrease as the width of the road decreases. The results of earlier work in Kenya by ABAYNAYAKA (1974) showed that speeds were significantly reduced on roads narrower than about 5 m so this effect was incorporated into the Model. The reduction of speed for light vehicles on paved roads is greater than for those running on unpaved roads, but for heavy vehicles the result is opposite to this.

Table 19 Speeds and Fuel Consumptions of Vehicles in Section I and Section II by the Model

Section I

Altitude (metres)		83.0					
Rise of road in m/km	outward	5	Fall of road in m/km		outward		7
	inward	7			inward		5
Vehicle type		PC	LT	HB	MT	HT	ST
Average speed in km/hr	outward	98	83	69	65	65	65
	inward	97	82	68	63	63	63
Fuel consumption L/1000km	outward	125	199	278	275	323	355
	inward	130	207	292	289	336	369
Fuel consumption km/L	outward	8.00	5.03	3.60	3.64	3.10	2.82
	inward	7.69	4.83	3.42	3.46	2.98	2.71
Lubricating oil consumption L/1000km		1.20	1.80	4.00	4.00	4.00	4.00

Section II

Altitude (metres)		39.0					
Rise of road in m/km	outward	2	Fall of road in m/km		outward		4
	inward	4			inward		2
Vehicle type		PC	LT	HB	MT	HT	ST
Average speed in m/km	outward	101	85	71	67	67	67
	inward	100	84	70	65	65	65
Fuel consumption L/1000km	outward	125	197	273	269	317	349
	inward	131	207	288	284	332	364
Fuel consumption km/L	outward	8.00	5.08	3.66	3.72	3.15	2.87
	inward	7.63	4.83	3.47	3.52	3.01	2.75
Lubricating oil consumption L/1000km		1.20	1.80	4.00	4.00	4.00	4.00

greater than 5.0 m. Consequently, there was no speed reduction due to road width. The average fall of road in Sections I and II was higher along the outward direction (increasing chainage) than along the inward direction, but the average rise of the road was lower along the outward direction than along the inward direction. Thus, the vehicle speed was higher in the outward direction. In order to obtain the components of vehicle operating cost, an average value of speed for each type of vehicle was determined.

Vehicle Operating Cost

The vehicle operating costs used in this study comprise the economic costs of maintaining and operating vehicles on the study road. Almost all of these data were based on VALLENTINE, LAURIE & DAVIES (1976) costs, except for the vehicle crew's time cost and the passenger or cargo time cost which were obtained from SINTHUSARN (1976). The Model divides road user cost into two categories: vehicle operating cost and time cost. The vehicle operating costs employed by the Model can be divided into two groups. The first group -- comprising those which remain constant throughout the analysis period -- consisted of fuel, lubricating oil, interest and crew's time costs. The second group -- which change for every year of analysis -- consisted of tyres, spare parts, vehicle maintenance labour, vehicle depreciation, and overhead and standing costs, as shown in Tables 20 and 21. The analy-

Table 20 Vehicle Operating Costs for Section I, Baht/km

Veh. Type	Year	Fuel	Lubricating Oil	Tyres	Spare Parts	Veh. Maint. Labour	Veh. Depreciation	Interest	Crew Time	Ohead and Standing Cost	Total User Cost
PC	3	0.2720	0.0102	0.0199	0.1047	0.0319	0.4677	0.2530	0	0.1159	1.2753
	14			0.0462	0.2335	0.0585	0.4545			0.1328	1.4606
	15			0.0092	0.0314	0.0107	0.4568			0.1043	1.1477
	17			0.0092	0.0383	0.0130	0.4501			0.1046	1.1504
LT	3	0.4322	0.0153	0.0329	0.1315	0.0531	0.2115	0.1144	0.4000	0.3477	1.7386
	14			0.0765	0.2716	0.0903	0.2085			0.4022	2.0108
	15			0.0152	0.0379	0.0172	0.2069			0.3098	1.5488
	17			0.0152	0.0508	0.0228	0.1982			0.3122	1.5611
HB	3	0.5444	0.0340	0.0908	0.0694	0.0348	0.3382	0.1725	1.0000	0.5710	2.8551
	14			0.1043	0.1426	0.0681	0.3320			0.5995	2.9974
	15			0.0814	0.0198	0.0103	0.3343			0.5492	2.7459
	17			0.0823	0.0245	0.0126	0.3293			0.5499	2.7494
MT	3	0.5381	0.0340	0.1962	0.4281	0.2050	0.6034	0.3078	1.1250	0.8594	4.2972
	14			0.2254	0.6793	0.3119	0.5414			0.9407	4.7036
	15			0.1760	0.3606	0.1777	0.5395			0.8147	4.0734
	17			0.1779	0.3783	0.1860	0.5309			0.8195	4.0975
HT	3	0.6293	0.0340	0.2611	0.6172	0.2563	0.5568	0.2840	0.6000	0.8096	4.0482
	14			0.2999	0.8636	0.3437	0.5632			0.9044	4.5220
	15			0.2342	0.4599	0.1965	0.5605			0.7496	3.7480
	17			0.2367	0.4789	0.2041	0.5545			0.7554	3.7768
ST	8	0.6915	0.0340	0.3603	0	0	6.6857	1,2940	0.5000	2.3914	11.9569
	9			0.3649	1.2891	0.0960	3.5353			1.9512	9.7560
	14			0.3920	7.3224	0.5330	1.9752			3.1855	15.9277
	15			0.3061	4.1978	0.3280	2.0130			2.3411	11.7056
	17			0.3094	3.3612	0.2620	2.2955			2.1869	10.9343

Table 21 Vehicle Operating Costs for Section II, Baht/km

Veh. Type	Year	Fuel	Lubricating Oil	Tyres	Spare Parts	Veh. Maint. Labour	Veh. Depreciation	Interest	Crew Time	Ohead and Standing Cost	Total User Cost
PC	3	0.2730	0.0102	0.0194	0.1027	0.0313	0.4677	0.2530	0	0.1157	1.2730
	17			0.0345	0.1700	0.0466	0.4579			0.1245	1.3698
LT	3	0.4305	0.0153	0.0321	0.1289	0.0522	0.2115	0.1144	0.4000	0.3462	1.7312
	17			0.0571	0.2316	0.0843	0.1991			0.3831	1.9154
HB	3	0.5354	0.0340	0.0905	0.0681	0.0341	0.3382	0.1725	1.0000	0.5682	2.8410
	17			0.0983	0.1105	0.0539	0.3299			0.5836	2.9181
MT	3	0.5280	0.0340	0.1957	0.4250	0.2037	0.6034	0.3078	1.1250	0,8556	4.2782
	17			0.2124	0.6002	0.2808	0.5379			0.9065	4.5327
HT	3	0.6191	0.0340	0.2603	0.6127	0.2546	0.5568	0.2840	0.6000	0.8054	4.0268
	17			0.2826	0.7734	0.3138	0.5526			0.8649	4.3243
ST	8	0.6813	0.0340	0.3481	0	0	6.6857	1.2940	0.5000	2.3858	11.9289
	9			0.3500	1.1655	0.0879	3.5353			1.9120	9.5600
	17			0.3695	7.4141	0.5501	1.6756			3.1296	15.6481

sis period of the present study was 17 years. The first and second years were the construction period. The third year was the first year in which the road was open to traffic, and the 17^{th} year was the last year of the analysis period. As overlaying took place in the 14^{th} year on Section I, it was decided to show the values of the components of vehicle operating costs in the 14^{th} and 15^{th} years in Table 20. Vehicle type ST (Semi-trailer) was forecasted to be in service on the study road in the 8^{th} year; therefore, this was used as the beginning year for this type of vehicle. From these two tables, it may be seen that tyres, spare parts and vehicle maintenance labour costs increased with the value of roughness as previously described. As roughness decreased, these costs decreased too, except for the vehicle depreciation cost which was found to be influenced by the vehicle-age spectrum predicted by the Model. A comparison of the differences in vehicle operating costs of Section I and of Section II can be summarized as follows.

There were no variations in lubricating oil, interest or crew time costs as the relevant input data for these elements were the same for the two sections. Fuel cost showed small differences because of differences in the road geometry. Costs for tyres, spare parts and vehicle maintenance were not greatly different at the beginning year; but, in subsequent years these costs showed larger differences because the deterioration of the two road sections was not the same. In Section I, overlaying took place in the 14th year because the roughness exceeded the limit set in the Model. Hence, without upgrading, the road could not be kept in service. Tyres, spare parts, and vehicle-maintenance labour cost decreased in the 15th year as a result of the new roughness value associated with the asphaltic-concrete overlay pavement. It should be emphasized strongly that the better type of pavement results in an important reduction in vehicle operating costs.

In order to make a comparison between the vehicle operating costs predicted by the Model with those of VALLENTINE, LAURIE & DAVIES (1976), the 3rd-year costs of the representative Section I were chosen. Table 22 compares the components of vehicle operating costs for each type of vehicle at the same range of speed. Fuel costs predicted by the Model for all vehicle types were all higher than the VL&D values. This was especially so for light trucks; a possible explanation is that the study vehicle used in Kenya to represent light commercial vehicles had a 1,600-cc engine which is larger than the 1,300-cc typical size of the VL&D study. Oil consumption costs predicted by the Model were all higher. As this cost was simply oil consumption multiplied by the unit cost of oil, the difference came from the unequally predicted oil consumption values as shown below.

Table 22 Comparison of Vehicle Operating Costs Predicted by the Model* with VL&D Study, Baht/km

Item	PC	LT	HB	MT	HT	ST
VALLENTINE, LAURIE & DAVIES						
Speed (kph)	88.0	80.0	72.0	64.0	64.0	64.0
Fuel	0.2173	0.2302	0.3823	0.3904	0.4881	0.6758
Oil	0.0090	0.0105	0.0200	0.0204	0.0204	0.0218
Tyres	0.0450	0.0509	0.0836	0.1624	0.2532	0.3545
Repairs and maintenance	0.1586	0.1889	0.3199	0.3546	0.5011	0.5441
Depreciation and interest	0.7384	0.2962	0.4200	0.7175	0.6859	3.1586
Sub-total	1.1684	0.7769	1.2261	1.6457	1.9490	4.7550
Overheads	0	0	0.0475	0.0723	0.0846	0.0846
Total	1.1684	0.7769	1.2736	1.7180	2.0336	4.8396
MODEL*						
Speed (kph)	97.5	82.5	68.5	64.0	64.0	64.0
Fuel	0.2720	0.4322	0.5444	0.5381	0.6293	0.6915
Oil	0.0102	0.0153	0.0340	0.0340	0.0340	0.0340
Tyres	0.0199	0.0329	0.0908	0.1962	0.2611	0.3649
Repairs and maintenance	0.1366	0.1846	0.1042	0.6331	0.8735	1.3851
Depreciation and interest	0.7207	0.3259	0.5107	0.9112	0.8408	4.8293
Sub-total	1.1594	0.9909	1.2841	2.3128	2.6386	7.3048
Crew time	0	0.4000	1.0000	1.1250	0.6000	0.5000
Overhead & standing cost	0.1159	0.3477	0.5710	0.8594	0.8096	1.9512
Total	1.2753	1.7386	2.8551	4.2972	4.0482	9.7560
Percent difference						
Fuel	+ 25	+ 88	+ 42	+ 38	+ 29	+ 2
Oil	+ 13	+ 46	+ 70	+ 67	+ 67	+ 56
Tyres	- 56	- 35	+ 9	+ 21	+ 3	+ 3
Repairs and maintenance	- 14	- 2	- 67	+ 78	+ 74	+154
Depreciation and interest	- 2	+ 10	+ 21	+ 27	+ 22	+ 53
Sub-total	- 1	+ 27	+ 5	+ 40	+ 35	+ 53
Total	+ 9	+124	+124	+150	+ 99	+101

*Section I, 3rd year of analysis

Vehicle Type	Oil Consumption in km/litre	
	Model	VL&D
PC	833	1,000
LT	555	770
HB	250	450
MT	250	450
HT	250	450
ST	250	450

It is obvious that tyre costs predicted by the Model for light vehicles were lower; but, for heavy buses and medium and heavy trucks their costs were slightly higher. For light vehicles, tyre cost was dominated by road roughness, but for heavy buses and medium and heavy trucks, tyres cost was influenced by both the road roughness and the gross vehicle weight. Costs of repairs and maintenance, and depreciation and interest could not be reasonably compared as there are differences in the methods used by the Model and by VL&D. VL&D used average characteristics of each vehicle type for the analysis, but the Model calculated the characteristics of each vehicle type by using the forecast traffic volume distributed into the vehicle-age spectrum. Obviously, this Model aims towards a realistic picture of the traffic. There were differences in the treatment of other components of vehicle operating cost between the Model and the VL&D study. The Model included crew-time cost as a component in vehicle operating costs, and included the overhead and standing cost for every type of vehicle. VL&D included the crew-time cost in addition to the passenger-time cost, and included the overhead costs for heavy commercial vehicles and buses. Thus, the overall ensemble of vehicle operating costs of the Model was higher than those of VL&D as shown in Table 22.

Time Cost

The Model enables the cost of passenger time (or cargo time) to be separated from the vehicle operating cost. Journey times were found from the road length and the vehicle speed and these were used to cost the passenger's time. Differences in the geometry of Section I and Section II resulted in different vehicle speeds and in differences in time costs. The time cost for Section I is higher because of lower speeds which resulted in longer journey times, as shown in Table 23.

Table 23 Passenger Time Costs for Section I and Section II, Baht/km

Vehicle Type	Section I	Section II
PC	0.3074	0.2995
LT	0.1211	0.1180
HB	0.7329	0.7100
MT	0.1093	0.1059
HT	0.1093	0.1059
ST	0.1093	0.1059

As data on the unit time cost for each vehicle type could not be deduced from the reports of VALLENTINE, LAURIE & DAVIES (1976), the present study used data from SINTHUSARN (1976) and compared the time costs as obtained from the Model with the values suggested to the Department of Highways by T.P.O'SULLIVAN & PARTNERS (1973) shown in Table 24.

Table 24 Comparison of Time Cost Predicted by the Model with the T.P.O'SULLIVAN Study, Baht/km

Vehicle Type	Model (Section I)	T.P.O'SULLIVAN	Percent Difference
PC	0.3074	0.3730	- 17
LT	0.1211	0.2240	- 46
HB	0.7329	0.8270	- 11
MT	0.1093	0.1640	- 33
HT	0.1093	0.1640	- 33
ST	0.1093	0.1640	- 33

The time costs calculated by the Model were all lower than the values from T.P.O'SULLIVAN. This is due to the Model assigning crew time cost as a component of vehicle operating cost, therefore excluding it from the time cost. An exception was made for passenger cars because there would be no crew time cost on this vehicle type, so the present study underestimated this cost for passenger cars. Nevertheless, as the time cost is entirely dependent upon the data, if the same source of data were used, there would only be a slight differences resulting from different values of predicted speeds.

Road Maintenance Cost

Because there were no data available concerning standard schedules and details for maintenance of rural roads, the present study used all the packages for maintenance operations from the default options of the Model and used plant-hire rates, labour rates, and material costs from SINTHUSARN (1976) whose data were obtained from the Department of Highways. Table 25 and Table 26 show the maintenance operations for Section I and Section II, respectively, and these operations are discussed in the following paragraphs.

Shoulder maintenance

Shoulder maintenance techniques used in the Model are based on the maintenance requirements developed in the MIT Model. Section I had unpaved shoulders with a paved surface of 6.5-m[1] width, thus the shoulder maintenance required by the Model con-

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[1]It was noticed during the Kenya study (HODGES, 1975) that if the width of the pavement running surface was greater than 6.5 m, traffic rarely encroached on the shoulders except in emergencies, whereas if the paved running surface was less than 6-m wide many of the lorries travelled with their near-side wheel overlapping the shoulder. The maintenance of the shoulders of roads which have a paved running surface wider than 6.5 m therefore consists of vegetation control (usually merely grass cutting) and, to ensure adequate surface drainage, grading of the loose gravel which accumulates at the edge of the pavement.

Table 25 Road Maintenance Output of Section I

Year	Maintenance Operations		Cost ฿	Annual Cost ฿
3-6	Shoulder mowing	area 72,000 m^2	3,820	
	Shoulder grading	area 76,800 m^2	1,722	
	Drainage maintenance	960 cu.m of sediment removed	10,072	
	Maintenance overheads		1,718	17,332
7	Light(surface)patching	area 526.3 m^2	8,221	
	Heavy (base) patching	area 526.3 m^2	15,981	
	Surface dressing	area 104,000 m^2	412,141	
	Shoulder mowing	area 72,000 m^2	3,820	
	Shoulder grading	area 76,800 m^2	1,722	
	Drainage maintenance	960 cu.m of sediment removed	10,072	
	Maintenance overheads		49,715	501,672
8-10	Same as in year 3			17,332
11	Light(surface)patching	area 1,262 m^2	19,699	
	Heavy (base) patching	area 1,262 m^2	38,296	
	Shoulder mowing	area 72,000 m^2	3,820	
	Shoulder grading	area 76,800 m^2	1,722	
	Drainage maintenance	960 cu.m of sediment removed	10,072	
	Maintenance overheads		8,097	81,706
12	Light(surface)patching	area 4,431 m^2	69,179	
	Heavy (base) patching	area 4,431 m^2	134,501	
	Surface dressing	area 104,000 m^2	412,141	
	Shoulder mowing	area 72,000 m^2	3,820	
	Shoulder grading	area 76,800 m^2	1,722	
	Drainage maintenance	960 cu.m of sediment removed	10,072	
	Maintenance overheads		69,458	700,892
13	Same as in year 3			17,332
14	Overlay (volume of materials 6,500 cu.m)	area 104,000 m^2	6,971,120	
	Shoulder mowing	area 72,000 m^2	3,820	
	Shoulder grading	area 76,800 m^2	1,722	
	Drainage maintenance	960 cu.m of sediment removed	10,072	
	Maintenance overheads		768,541	7,755,275
15-16	Same as in year 3			17,332
17	No road maintenance			0

Table 26 Road Maintenance Output of Section II

Year	Maintenance Operations		Cost ฿	Annual Cost ฿
3-6	Shoulder grading	area 118,800 m^2	2,669	
	Drainage maintenance	1,782 cu.m of sediment removed	18,696	
	Maintenance overheads		2,350	23,715
7	Surface dressing	area 178,200 m^2	722,195	
	Shoulder grading	area 118,800 m^2	2,669	
	Drainage maintenance	1,782 cu.m of sediment removed	18,696	
	Maintenance overheads		81,792	825,352
8-11	Same as in year 3			23,715
12	Surface dressing.	area 178,200 m^2	722,195	
	Shoulder grading	area 118,800 m^2	2,669	
	Drainage maintenance	1,782 cu.m of sediment removed	18,696	
	Maintenance overheads		81,792	825,352
13-16	Same as in year 3			23,715
17	No road maintenance			0

sisted of a single edge-grading each year (graded area was assumed to be 4,800 m^2/km) and grass mowing, The number of grass mowings required by the Model is one for every 500 mm of annual rainfall, and the complete width of the shoulder is assumed to be at such times. Section II had unpaved shoulders with a paved surface of 6.0-m width, the shoulder maintenance as required by the Model consisted of one edge grading each year and no shoulder mowing because the shoulders would be in service from time to time by the heavy vehicles.

Drainage maintenance

The Model used the equation from the MIT Highway Cost Model to estimate the amount of sediment to be removed each year, as shown in Tables 25 and 26. This type of maintenance was specified in order to keep side drains and culverts in good condition.

Patching

The Model assumed that the depth of all patching would extend to the bottom of the base layer of the pavement and for costing purposes, patching was separated into one for the base material (Heavy base patching) and another for the surfacing (Light surface patching). The amount of patching is assumed to be independent of road width for two-lane roads wider than about 6 metres. As it is unlikely that paved roads would be designed with widths less than 6 metres, patching was assumed in the Model to be independent of road width. Whenever pavement cracking exceeds 5 m/m^2, the Model decrees that patching is needed. In Section I the Model predicted that patching would be required in the 7^{th}, 11^{th}, and 12^{th} years.

Surface dressing

The present study used re-surface-dressing as the maintenance policy, so the Model would provide the study road with this type of maintenance whenever one of the following limits was exceeded:

a) the mean cracking in the wheel tracks on either side of the road reached 1 m/m^2;

b) five years had elapsed since the previous surface dressing; or

c) the traffic loading since the previous surface dressing reached 1.5-million equivalent axles in either direction.

The Model predicted that the limit of time would be exceeded first for both Section I and Section II. Therefore, surface dressing would take place at five-year intervals: the 7^{th} and 12^{th} years.

Overlaying

The data obtained in Kenya indicated that the amount of cracking was approximately a linear function of the traffic loading, prior to its value exceeding 3 m/m^2. Therefore, the Model used this limit as a threshold condition at which overlaying would be required for a pavement which was not re-surface-dressed under routine maintenance. The present study specified re-surface-dressing as part of the normal maintenance policy, so the average cracking was not allowed to exceed 1 m/m^2. Then the limit of roughness became the threshold condition at which an overlay would be required for the pavement. A roughness value of 4,000 mm/km was used in the present study as a maximum limit for both Section I and Section II. The Model predicted that only Section I would reach this roughness limit. This would occur in the 14^{th} year at which time overlaying would be carried out to extend the life of the road.

Overheads and supervision costs

The overheads and supervision costs used in the Model were taken as a percentage of the total maintenance cost for completeness of the program. The present study used 11 percent for this item for both Section I and Section II.

Comparison of road maintenance costs

The cost of maintaining bitumen roads suggested by VL&D for the Ban Bung-Khai Feeder Road can be listed under the following four headings.

(1) General maintenance of right-of-way, clearing drains, cutting grass, repairs to road furniture, lane markings, etc. These costs are fixed per kilometre of road; they are dependent upon the general topography and climatic conditions. Therefore, they are not related to the amount of traffic using the road.

(2) Maintenance of shoulders; the shoulders of bitumen roads in Thailand are frequently of lateritic or gravel materials. As a result of vehicles encroaching onto the shoulders from time to time, some material is lost, so replacement of material and reshaping is required. These costs were based on the predicted amount of encroachment by vehicles for various traffic volumes and carriageway widths.

(3) Maintenance of the bitumen surface such as repair of pot holes and damaged carriageway edges. The cost of repairing pot holes (the same as patching of the Model) was used as a fixed cost, but the cost of edge maintenance is related to the volume of traffic and the carriageway width as shoulder maintenance in item (2).

Totalling these three items of cost -- using the estimated labour, plant, and materials requirements for the conditions existing in the route corridor -- resulted in determination by VL&D of the following formulas.

Road Class	Carriageway Width	Formula
F_2	6.5 m	C = 7,900 + 0.3Q
F_3	6.0 m	C = 7,900 + 0.4Q

where C = economic cost of maintenance of bitumen road in Baht/km

Q = number of vehicles per day, excluding motorcycles, using a road

(4) Periodic resealing of the surface: it was necessary to determine the frequency with which resurfacing should take place and the following periods of surface treatment were used.

For primed and double surface dressed roads

Up to	250	vpd	-	7 year
From	250-500	vpd	-	6 years
From	500-1,000	vpd	-	5 years
From	1,000-3,000	vpd	-	4 years.

When the traffic at the time of resurfacing exceeds 3,000 vpd, the provision of a 25-mm thick wearing course of bitumen concrete is used at intervals of 12 years. The ADT of Section I and Section II did not exceed 3,000 vpd, therefore the costs of surface dressing for these sections were determined by VL&D as follows.

Road Class	Carriageway Width	Surface-Dressing Cost, Baht per km
F_2	6.5 m	100,000
F_3	6.0 m	93,000

Table 27 shows the calculated annual maintenance costs of Section I and Section II using the formulas proposed by VL&D.

Table 27 Calculated Annual Maintenance Costs of Section I and Section II Using Formulas Proposed by VL&D, Baht

Year	ADT	Cost Items (1)+(2)+(3)	Cost Item (4)	Annual Cost	Total Cost
Section I (16.0 km)					
1979	574	129,155	-	129,155	
1980	648	129,510	-	129,510	
1981	720	129,856	-	129,856	
1982	794	130,211	-	130,211	
1983	867	130,562	1,600,000	1,730,562	
1984	943	130,926	-	130,926	
1985	1,040	131,392	-	131,392	
1986	1,135	131,848	-	131,848	
1987	1,232	132,314	1,600,000	1,732,314	
1988	1,328	132,774	-	132,774	
1989	1,425	133,240	-	133,240	
1990	1,552	133,850	-	133,850	
1991	1,681	134,469	1,600,000	1,734,469	
1992	1,811	135,093	-	135,093	
1993	1,941	135,717	-	135,717	6,780,917
Section II (29.7 km)					
1979	464	240,142	-	240,142	
1980	548	241,140	-	241,140	
1981	631	242,126	-	242,126	
1982	715	243,124	-	243,124	
1983	797	244,098	2,762,100	3,006,198	
1984	882	245,108	-	245,108	
1985	1,003	246,546	-	246,546	
1986	1,124	247,983	-	247,983	
1987	1,245	249,421	2,762,100	3,011,521	
1988	1,365	250,846	-	250,846	
1989	1,487	252,296	-	252,296	
1990	1,653	254,268	-	254,268	
1991	1,823	256,287	2.762,100	3,018,387	
1992	1,990	258,271	-	258,271	
1993	2,161	260,303	-	260,303	12,018,259

Table 28 compares the total maintenance costs of the Ban Map Pu-Ban Khai Feeder Road. It can be seen that the maintenance cost predicted by the Model displayed a higher value for Section I (resulting from the cost of overlaying: 7.75 millions Baht), a lower value for Section II, and a lower value for the combination of Sections I & II. Excluding the maintenance cost of periodic surface dressing and overlaying, the annual maintenance costs predicted by the Model (shown in Table 29) were less than one-seventh of those obtained using the VL&D method (shown in Table 27). Maintenance operations for both the Model and the VL&D method seem to be carried out similarly, but the costs displayed large differences. Discussion of these differences could not be reasonably made as there were no details about the components of maintenance operations described by VL&D.

Table 28 Comparison of Maintenance Costs of Ban Map Pu-Ban Khai Feeder Road, Baht

Item	Section I	Section II	Sections I & II
Model	9,212,865	1,935,284	11,148,149
VL&D Method	6,780,917	12,018,259	18,799,176
Percent difference from VL&D	+35.9	-83.9	-40.7

Total Transportation Cost

The total cost of transportation is made up of the road cost and road user cost. Road cost consists of amortized construction cost and the annual maintenance cost. Road user cost consists of the annual vehicle operating cost and the annual time cost. The analysis of the Ban Map Pu-Ban Khai Feeder Road was carried out for a period of 15 years, excluding the two-year construction period which was assumed to be 1977 and 1978. Fifty percent of the construction costs were assigned to each of these two years. All the unit rates applied in the analysis were referred to August 1974 prices in term of economic rates. The discount rate used was 12 percent; and this was the same as the rate of interest on borrowed capital to purchase a vehicle. Table 29 gives breakdowns of the total transportation costs for Section I and Section II; the combination of these two sections is shown in Table 30. All costs were converted to their present worth at the beginning of 1975 with 12 percent discount rate as shown in Table 31, 32, and 33 for Section I, II, and their combination, respectively. It is obvious from Table 33 that the maintenance cost of the Ban Map Pu-Ban Khai Feeder Road is only a small portion (about one percent) of the total transportation cost; construction cost is about 21 percent; and road user cost, including time cost, is the highest portion of 78 percent. Research on this RTIM Model was recently conducted for a primary

Table 29 Total Transportation Cost of Section I and Section II

Baht

Year	Construction	Maintenance	Vehicle Operation	Time
Section I				
1977	14,490,235	-	-	-
1978	14,490,235	-	-	-
1979		17,332	9,569,600	864,929
1980		17,332	10,626,128	1,003,480
1981		17,332	11,586,255	1,138,200
1982		17,332	12,561,636	1,276,752
1983		501,672	13,514,053	1,412,180
1984		17,332	14,660,670	1,553,164
1985		17,332	16,010,137	1,712,682
1986		17,332	17,372,390	1,870,854
1987		81,706	18,810,603	2,030,442
1988		700,892	20,271,024	2,190,409
1989		17,332	21,809,884	2,349,996
1990		7,755,275	23,772,626	2,559,495
1991		17,332	21,209,008	2,775,069
1992		17,332	22,709,035	2,986,621
1993		0	24,158,457	3,202,833
	28,980,470	9,212,865	258,641,506	28,927,106
	8.90%	2.83%	79.39%	8.88%
	Total cost	= 325,761,947		
Section II				
1977	22,686,887	-	-	-
1978	22,686,887	-	-	-
1979		23,715	13,498,887	1,300,554
1980		23,715	15,380,714	1,583,429
1981		23,715	17,072,262	1,863,057
1982		23,715	18,689,108	2,143,833
1983		825,352	20,263,011	2,422,183
1984		23,715	22,161,646	2,706,074
1985		23,715	24,625,838	3,074,288
1986		23,715	27,091,526	3,449,050
1987		23,715	29,563,200	3,812,813
1988		825,352	32,028,842	4,179,747
1989		23,715	34,620,336	4,557,756
1990		23,715	38,156,315	5,065,091
1991		23,715	41,765,395	5,585,796
1992		23,715	45,229,520	6,094,409
1993		0	48,900,298	6,616,262
	45,373,774	1,935,284	429,046,898	54,454,342
	8.55%	0.36%	80.83%	10.26%
	Total cost	= 530,810,298		

Table 30 Total Transportation Cost of Ban Map Pu-Ban Khai Feeder Road (Section I&II), Baht

Year	Construction	Maintenance	Vehicle Operation	Time
1977	37,177,122	-	-	-
1978	37,177,122	-	-	-
1979		41,047	23,068,487	2,165,483
1980		41,047	26,006,842	2,586,909
1981		41,047	28,658,517	3,001,257
1982		41,047	31,250,744	3,420,585
1983		1,327,024	33,777,064	3,834,363
1984		41,047	36,822,316	4,259,238
1985		41,047	40,635,975	4,786,970
1986		41,047	44,463,916	5,319,904
1987		105,421	48,373,803	5,843,255
1988		1,526,244	52,299,866	6,370,156
1989		41,047	56,430,220	6,907,752
1990		7,778,990	61,928,941	7,624,586
1991		41,047	62,974,403	8,360,865
1992		41,047	67,938,555	9,081,030
1993		0	73,058,755	9,819,095
	74,354,244	11,148,149	687,688,404	83,381,448
	8.68%	1.30%	80.28%	9.74%

Total cost = 856,572,245

Table 31 Total Transportation Cost of Section I, Present Worth in 1975 (12% discount rate), Baht

Year	Construction	Maintenance	Vehicle Operation	Time	Cumulative		
					Maintenance	Vehicle Operation	Time
1977	10,313,884	-	-	-	-	-	-
1978	9,208,831	-	-	-	-	-	-
1979		9,835	5,430,068	490,786	9,835	5,430,068	490,786
1980		8,781	5,383,553	508,397	18,616	10,813,621	999,183
1981		7,840	5,241,062	514,867	26,456	16,054,683	1,514,050
1982		7,000	5,073,465	515,662	33,456	21,128,148	2,029,712
1983		180,909	4,873,335	509,250	214,365	26,001,483	2,538,962
1984		5,580	4,720,378	500,081	219,945	30,721,861	3,039,043
1985		4,983	4,602,570	492,359	224,928	35,324,431	3,531,402
1986		4,449	4,459,098	480,206	229,377	39,783,529	4,011,608
1987		18,725	4,310,946	465,329	248,102	44,094,475	4,476,937
1988		143,418	4,147,895	448,206	391,520	48,242,370	4,925,143
1989		3,167	3,984,627	429,340	394,687	52,226,997	5,354,483
1990		1,265,068	3,877,874	417,514	1,659,755	56,104,871	5,771,997
1991		2,524	3,089,009	404,178	1,662,279	59,193,880	6,176,175
1992		2,254	2,953,110	388,384	1,664,533	62,146,990	6,564,559
1993		0	2,804,997	371,875	1,664,533	64,951,987	6,936,434
	19,522,715	1,664,533	64,951,987	6,936,434	Total cost = 93,075,669		
	20.98%	1.79%	69.78%	7.45%	100%		

Table 32 Total Transportation Cost of Section II, Present Worth in 1975 (12% discount rate), Baht

Year	Construction	Maintenance	Vehicle Operation	Time	Cumulative Maintenance	Cumulative Vehicle Operation	Cumulative Time
1977	16,148,110	-	-	-	-	-	-
1978	14,417,965	-	-	-	-	-	-
1979		13,457	7,659,660	737,972	13,457	7,659,660	737,972
1980		12,015	7,792,387	802,218	25,472	15,452,047	1,540,190
1981		10,728	7,722,667	842,757	36,200	23,174,714	2,382,947
1982		9,578	7,548,263	865,863	45,778	30,722,977	3,248,810
1983		297,632	7,307,093	873,469	343,410	38,030,070	4,122,279
1984		7,636	7,135,509	871,290	351,046	45,165,579	4,993,569
1985		6,818	7,079,399	883,792	357,864	52,244,978	5,877,361
1986		6,087	6,953,780	885,293	363,951	59,198,758	6,762,654
1987		5,435	6,775,188	873,807	369,386	65,973,946	7,636,461
1988		168,885	6,553,803	855,268	538,271	72,527,749	8,491,729
1989		4,333	6,325,073	832,694	542,604	78,852,822	9,324,423
1990		3,868	6,224,192	826,235	546,472	85,077,014	10,150,658
1991		3,454	6,082,967	813,549	549,926	91,159,981	10,964,207
1992		3,084	5,881,701	792,524	553,010	97,041,682	11,756,731
1993		0	5,677,730	768,203	553,010	102,719,412	12,524,934
	30,566,075	553,010	102,719,412	12,524,934	Total cost = 146,363,431		
	20.88%	0.38%	70.18%	8.56%	100%		

Table 33 Total Transportation Cost of Ban Map Pu-Ban Khai Feeder Road, Present Worth in 1975 (12% discount rate), Baht

Year	Construction	Maintenance	Vehicle Operation	Time	Cumulative		
					Maintenance	Vehicle Operation	Time
1977	26,461,995	-	-	-	-	-	-
1978	23,626,795	-	-	-	-	-	-
1979		23,292	13,089,728	1,228,758	23,292	13,089,728	1,228,758
1980		20,796	13,175,940	1,310,615	44,088	26,265,668	2,539,373
1981		18,568	12,963,729	1,357,624	62,656	39,229,397	3,896,997
1982		16,578	12,621,728	1,381,525	79,234	51,851,125	5,278,522
1983		478,541	12,180,428	1,382,719	557,775	64,031,553	6,661,241
1984		13,216	11,855,887	1,371,371	570,991	75,887,440	8,032,612
1985		11,801	11,681,969	1,376,151	582,792	87,569,409	9,408,763
1986		10,536	11,412,878	1,365,499	593,328	98,982,287	10,774,262
1987		24,160	11,086,134	1,339,136	617,488	110,068,421	12,113,398
1988		312,303	10,701,698	1,303,474	929,791	120,770,119	13,416,872
1989		7,500	10,309,700	1,262,034	937,291	131,079,819	14,678,906
1990		1,268,936	10,102,066	1,243,749	2,206,227	141,181,885	15,922,655
1991		5,978	9,171,976	1,217,727	2,212,205	150,353,861	17,140,382
1992		5,338	8,834,811	1,180,908	2,217,543	159,188,672	18,321,290
1993		0	8,482,727	1,140,078	2,217,543	167,671,399	19,461,368
	50,088,790	2,217,543	167,671,399	19,461,368	Total cost = 239,439,100		
	20.92%	0.92%	70.03%	8.13%	100%		

highway in Thailand by SINTHUSARN (1976). His analysis led to the following conclusion.

"Vehicle operating costs over a nine-year period of service were found to be about 85 percent, road maintenance costs less than 1 percent, and construction costs about 15 percent of the total cost of transportation."

From the preceding quotation, it may be seen that percentage of vehicle operating cost was higher for the primary highway than for the feeder road studied in the present research. The differences in percentage apportionment of total cost of transportion may be analysed as follows.

Fig. 6 shows the postulated relationships between the annual amortized construction and road maintenance cost, the annual vehicle operating cost, and isopleths of traffic volume (T_1, T_2, ...T_n). Line P represents the minimum amortized cost at which a road could be constructed and maintained. Point X represents the value of vehicle operating cost for traffic T_1 on a road annually costing amount C_c. Line Q represents the lower limit of vehicle operating cost which would result from T_1 vehicles travelling along the best quality road of the lowest standard. It is known that the best quality of road would require the expenditure of the highest level of road cost. However, as the amortized road cost increases, it is postulated that the vehicle operating cost decreases. For example, in Section I of the study road in the present research, the expenditure of an addi-

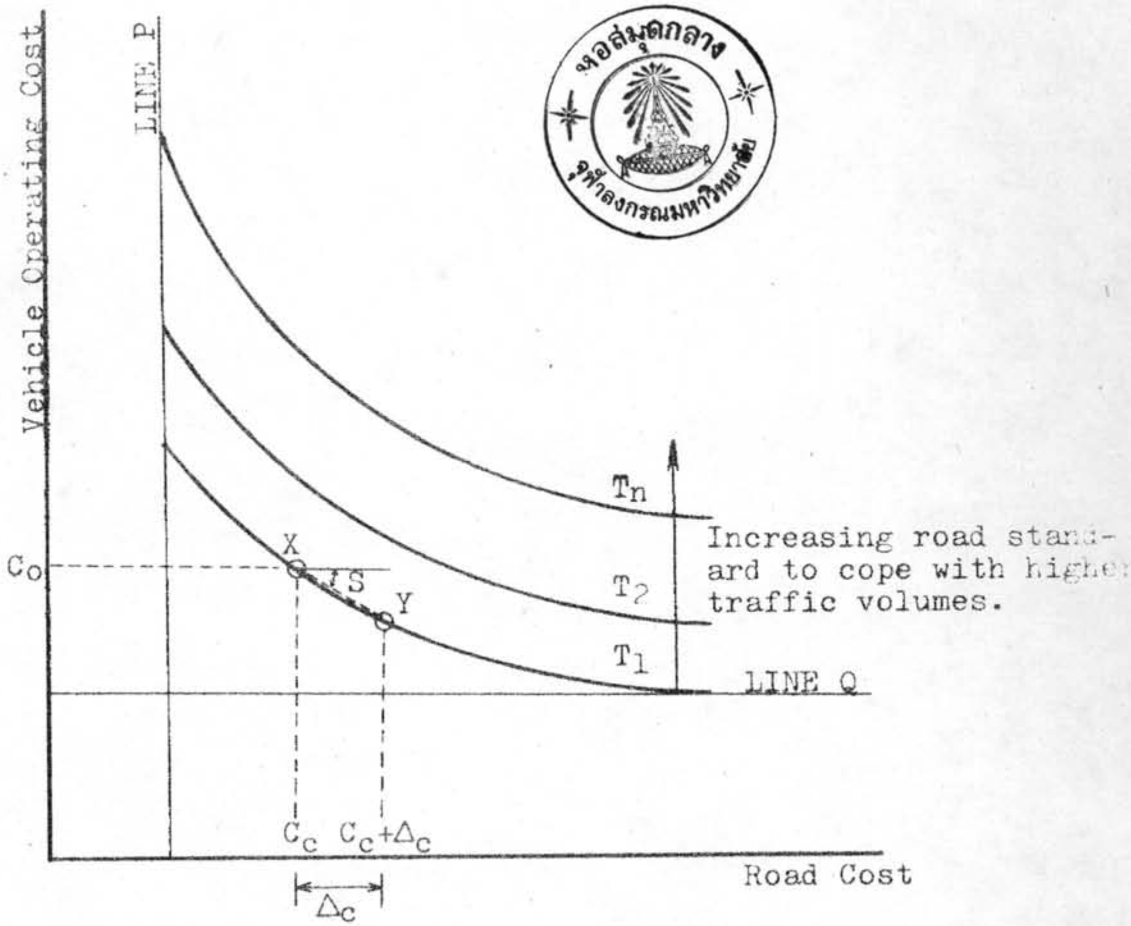

Fig. 6 Vehicle Operating Cost and Road Cost Curves

tional road cost for an asphaltic-concrete overlay on the existing surface-dressed pavement resulted in a reduction of vehicle operating cost. If Δ_c, an additional road cost, were spent to upgrade the road, the new relationship between road cost and vehicle operating cost would be represented by point Y. It is believed that the locus of points X....Y is hyperbolic with line Q as one of its asymptotes.

At point X: $$\frac{\text{Vehicle Operating Cost}}{\text{Total Transportation Cost}} = \frac{C_o}{C_o+C_c} \quad (1)$$

At point Y: $$\frac{\text{Vehicle Operating Cost}}{\text{Total Transportation Cost}} = \frac{C_o+S(\Delta_c)}{C_o+S(\Delta_c)+C_c+\Delta_c} \quad (2)$$

where S = slope of the secant connecting X and Y, and

Δ_c = additional road cost.

To compare Eq. (2) with Eq. (1), we can write:

$$\frac{C_o-j}{C_o+C_c-j} \longrightarrow 0 \text{ as } j \longrightarrow C_o$$

and $$\frac{C_o}{C_o+C_c+k} \longrightarrow 0 \text{ as } k \longrightarrow \infty$$

So, increasingly negative values of $S(\Delta_c)$ (represented by j), and increasingly positive values of Δ_c (represented by k), would lead to point Y having a lower ratio of vehicle operating cost to total transportation cost than point X for the descending part of any of the curves shown in Fig. 6. That is, the ratio decreases, for a given volume of traffic, as the quality of the road improves. Thus, for a given volume of traffic, it would be concluded that a higher road cost would result in a lower ratio of vehicle operating cost to total transportation cost.

The descending property of the curves shown in Fig. 6 arises from the notion that a better quality road (having a higher road amortization cost) would result in a lower vehicle operating cost for a given volume of traffic on that road. While this is probably true for most situations, it may not be generally true. For example, if the chief gain rendered by the better quality road were an increase in the operating speed of vehicles, there could result a positive-slope relationship between road cost and vehicle operating cost. This could stem from occupants' time having a low value, coupled with a high cost of fuel (the consumption of which increases with speed). However, for Section I of the present study road, overlaying with asphaltic-concrete pavement in the 14th year resulted in a substantial reduction in vehicle operating cost. Thus, the notion of a descending (negative slope) curve is applicable to the Ban Map Pu-Ban Khai Feeder Road. In the previous study of a primary highway (SINTHUSARN, 1976) large values of traffic growth in the latter portion of the analysis period seem to have masked the beneficial influence of large expenditures for pavement upgrading. The comparison between the feeder road with

Sinthusarn's primary highway is further complicated by the addition of the value of time to the vehicle operating cost in these analysis. Nonetheless, the ratio of (veh.op.cost + time cost)/(total transp.cost) for both the feeder road (78%) and the primary highway (87%) are remarkably close.

Vehicle operating cost is directly proportional to the amount of traffic forecast to travel on the road. Generally, road class is associated with traffic volume; thus, a higher standard road would basically be used for a higher traffic volume. Thus, the relationship between vehicle operating cost and amortized road cost for a given level of traffic volume would likely be one of a family of curves as shown in Fig. 6.

It is recommended that further research be conducted on the consistency of the ratio of vehicle operating cost to total tranportation cost for primary highways and feeder roads. Of course, the main thrust should be to provide guidance in selecting a road planning strategy that would minimize the denominator of Eq. (2), (that is, to minimize the total transportation cost). This occurs where S is at its greatest negative value for a given level of traffic in the postulated relationships, which themselves need further study.

Nevertheless, the use of the RTIM Model in the present research resulted in a reasonable apportionment of the total transportation cost. An analysis by WINFREY (1969) led to the following conclusion:

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