Chapter III

APPLICATION OF THE MODEL TO THE BAN BUNG-BAN KHAI FEEDER ROAD

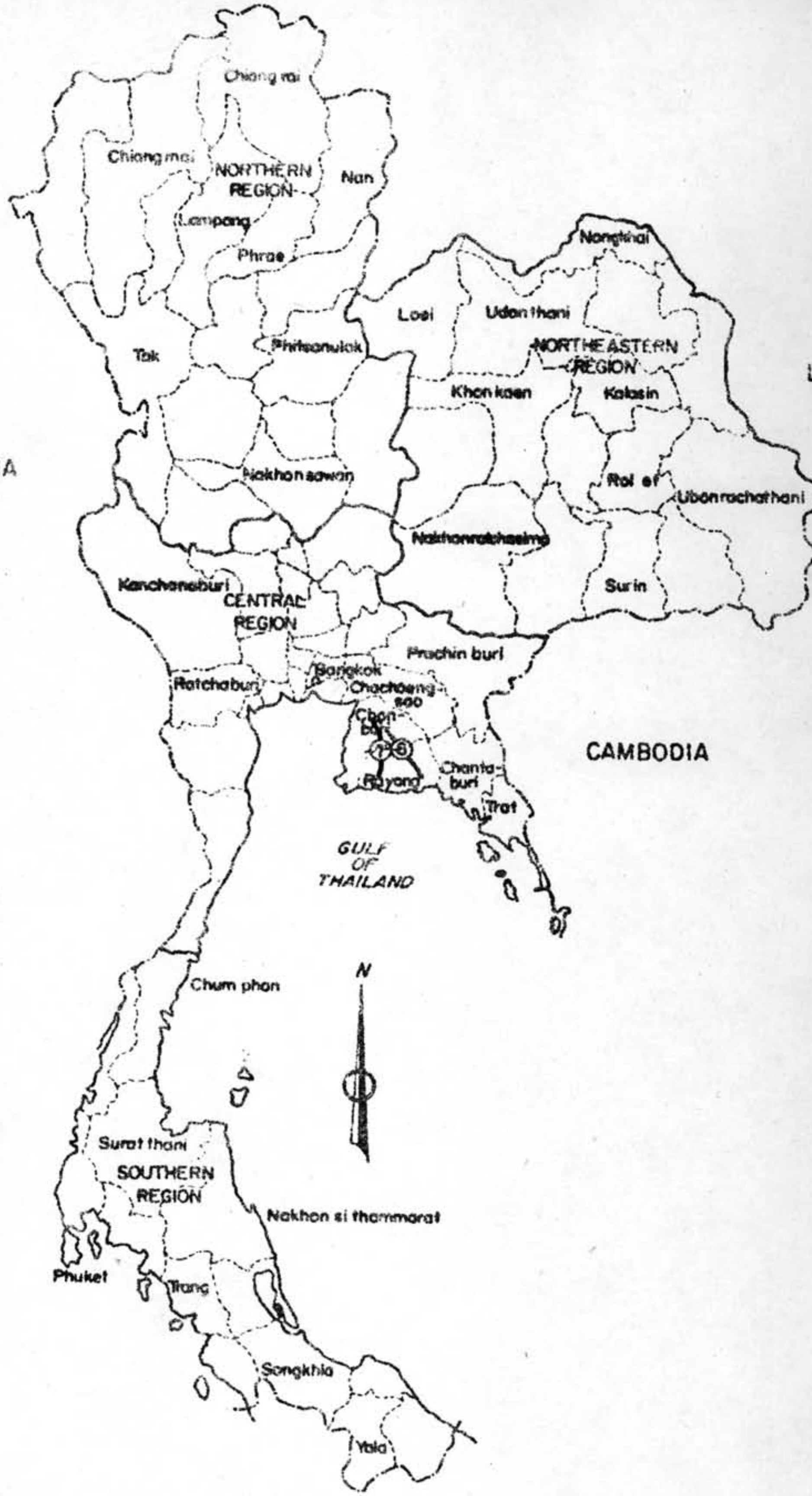
General Description of the Region

The Ban Bung-Ban Khai feeder road is situated in the south-eastern part of Thailand as shown in Fig. 1. Apart from major centres of urban population on or near the coast -- at places such as Chon Buri, Rayong and Chanthaburi -- a deep-water port at Sattahip, an oil refinery at Si Racha, and resort developments forming small communities along the coast, the economy of the region is largely based on agriculture.

Location

From Amphoe Ban Bung on Highway 3133 to Changwat Rayong on Highway 3, there exists a feeder road designated Highway 3138 which is mainly laterite surfaced and is poorly maintained. Amphoe Ban Khai is 10 kilometres north of Changwat Rayong along this road. The distance between Ban Bung and Ban Khai along this old road is about 70 kilometres. VALLENTINE, LAURIE & DAVIES (1976), under a contract with the Highway Department, designed new alignment and pavement for this road, making use of 3.5 kilometres of Highway 331 (called the Military Highway) at Ban Map Pu as a part of this feeder road alignment. Obviously, this

FIGURE 1



MAP OF THAILAND

feature makes the route look like two separate feeder roads joined by Highway 331, ie, the western portion being Ban Bung to Ban Map Pu and the eastern portion being Ban Map Pu to Ban Khai. For the present research, it was deemed realistic to study the longer portion which starts from Ban Map Pu at chainage 25+000 km and ends at Ban Khai at chainage 70+700 km as a representative route for application of the RTIM Model. The route distance in the present study, between Ban Map Pu and Ban Khai, is 45.7 kilometres.

Topography

The terrain of the area is generally flat to rolling with scattered hills and several nearby mountain ranges. The mountainous parts are mainly grouped in ranges running in a predominantly north/north-westerly direction. The waterways consist mostly of small streams running to the south coast. The Ban Map Pu-Ban Khai feeder road is situated between ranges of mountains.

Climate and vegetation

Southeastern Thailand has a monsoonal climate with marked wet and dry seasons. Each season lasts for a period of approximately six months. The wet season begins in April and ends in October. The average annual rainfall ranges from 1,200 mm in the northwest of the region to 2,400 mm in the southwest, with 3,000 mm near the mountains in the east. During the dry months, the rainfall does not exceed 60 mm per hour. The mean monthly temperature ranges between 34° C and 27° C. The average relative humidity during the year is around 75 percent. These climatic conditions do not limit plant growth, and it is possible to produce a wide range of long season upland crops and some perennial tree crops. Tropical rain forest occurs in some of the mountainous areas. The plains in the route corridor are mostly under cultivation; the principal crops are cassava and sugar. Complementary industrial activity, mainly at sugar mills and at cassava drying pads, occurs within the route corridor. Approximately 80 percent of the area is undulating land having slopes less than 10 percent and having drainage and soil conditions suitable for the production of upland crops. Much of the area in Changwad Rayong is officially designated as forest reserve but over the years more and more forest has been cleared and replaced by cassava plantations.

Geology

Generally, the mountain ranges are of older granitic formations with many intrusions of limestone of the Korat series, together with some Rajburi limestone and gneiss and schists. In the route corridor, 50 percent is older granite of the western mountain range and the rest is alluvial deposits. The soils in the area are mainly sands or sandy loams overlying clays. Most of the land in the route corridor is already cultivated and the agricultural potential of the soils can be established in terms of crop yields.

Transport system

The transport network in the area including the route corridor is basically a highway network. Bangkok acts as the major trip generator and most major routes lead towards the capital. The principal highway in the network is Highway 3 (Sukhumvit Highway), a designated Primary Highway in the Department of Highways' National Road System. The network includes Secondary Highway 331 (known locally as the "Military Highway" as it was constructed by U.S.Forces). The principal highways in the transport network, together with the main towns and villages, are shown in Fig. 2.

Road transport comprises the only significant transport mode in the area. There is some coastal shipping but this does not compete with road transport in the upland area. There are no canals in or near the route corridor and the nearest rail link runs in an east-west direction outside and to the north of the area. Transportation within the area is entirely dependent

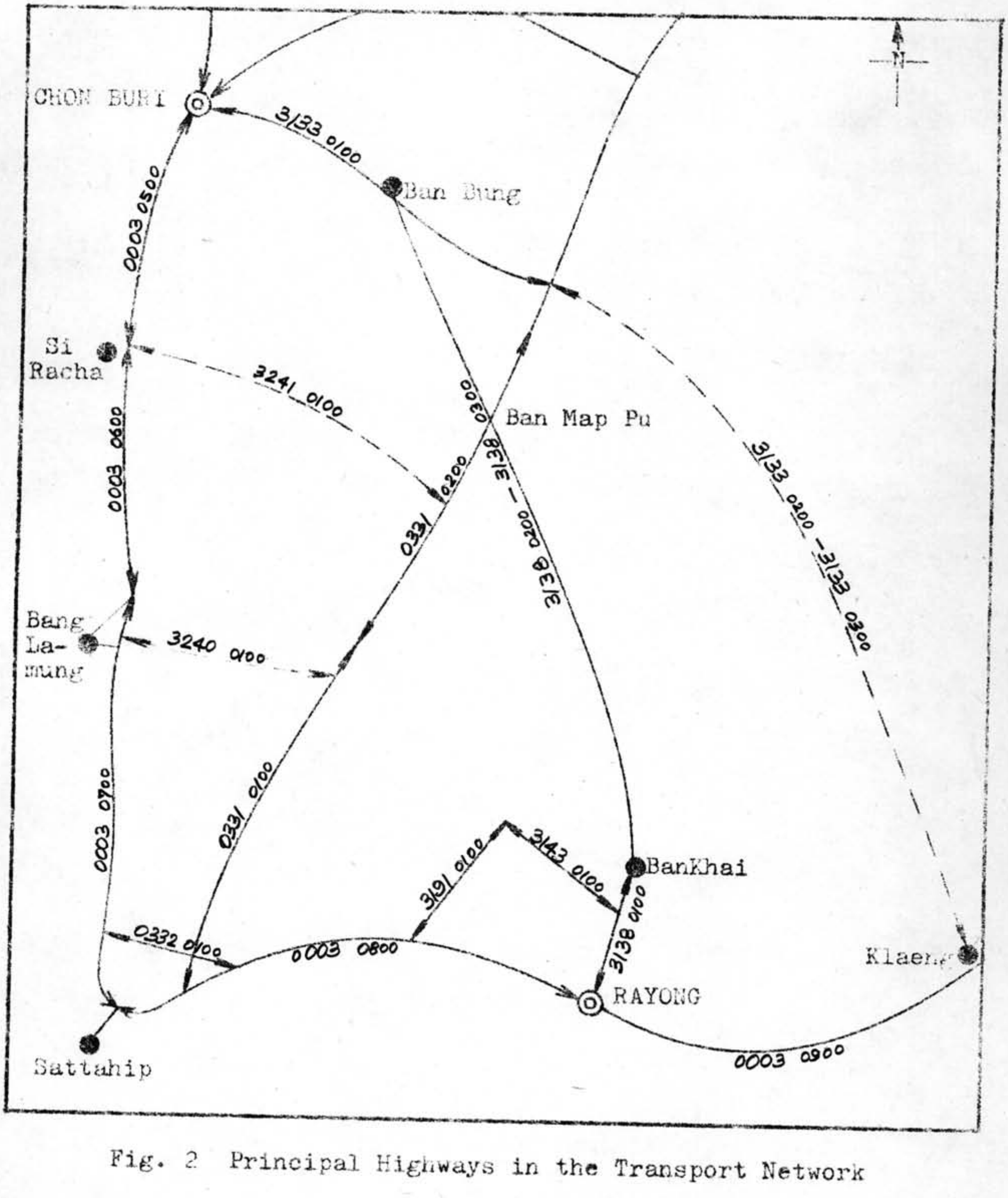


Fig. 2 Principal Highways in the Transport Network

on the road network. Private transport companies can be expected to grow to satisfy an increasing demand for their services. The extent to which this will be possible will depend largely on credit possibilities for the purchase of large trucks for the more efficient transport of resource commodities and, to a lesser extent, upon the improvement of the secondary and tertiary road network.

Economy

Agriculture is the dominant economic activity of the region. Over 85 percent of the residents are engaged in farming, and the villages and towns in the area are principally service and marketing centres for the farmers. The area of influence to the west is dominated by Bangkok. Westbound traffic to Bangkok carries bulky primary products for processing, consumption, or export, and overshadows the eastbound traffic of construction materials and consumer goods. The ocean to the south, the Cambodian border to the east, and the relatively less developed northeastern region tend to inhibit commodity or trade flows in those directions; hence, for commercial purposes, the area is oriented in the direction of Bangkok.

The economic base of the area is essentially agriculture with minor processing industries such as sugar mills, cassava drying plants, saw mills, rice mills, slaughter houses, etc., which process local agricultural products almost exclusively. The various products are marketed through different channels, but they all have a common feature in that commodities destined for export are sent to Bangkok. The possibility of establishing an export centre at the former U.S. military seaport at Sattahip offers an exciting alternative to the historical predominance of Bangkok.

Traffic Classification

Traffic was divided into five categories by VALLENTINE, LAURIE & DAVIES (1976), namely: normal, generated, developmental, diverted, and special traffic. From observations made of types of vehicles operating on the existing roads in the area and on adjacent roads which could give rise to diverted traffic, the following nine classes were adopted by VL&D.

Class 1 motorcycles (MC)
Class 2 passenger cars, including taxis (PC)
Class 3 four-wheel drive vehicles (4-W)
Class 4 light trucks (LT)
Class 5 medium trucks (MT)
Class 6 heavy trucks (HT)
Class 7 light buses (LB)

Class 8 heavy buses (HB)

Class 9 semi-trailers (ST)

Motorcycles have been included because of the high proportion of them, both as a percentage of the total vehicles registered and in the present road traffic mix, on the study road. In order to define the cost elements for each vehicle class -- such as fuel, oil and lubricants, tyres, repairs and maintenance, depreciation and interest, and overheads -- representative type vehicles were selected for each of the nine vehicle classes adopted. The pertinent characteristics of these representative vehicles are shown in Table 3.

Road Links and Road Standards

Road links are defined as sections of roads with uniform characteristics of road geometry and traffic. They are employed to simplify the computation of road user costs. As the country is flat to rolling throughout the proposed road alignment, the selection of links depended entirely on the traffic. Road links defined by VALLENTINE, LAURIE & DAVIES (1976) between Ban Map Pu and Ban Khai are as shown in Fig. 3.

The Department of Highways has determined five feeder-road standards based on traffic volumes (excluding motorcycles) as shown in Table 4. Below 200 vehicles per day, a gravel surface only is required. Above that figure, a bituminous surface is to

Table 3 Summary of Data Used for Calculating Vehicle Operating Costs

Veh. class	1	2	3	4	5	6	7	8*	8	9
Veh. type	Motor cycle	Car	4wheel drive	Light truck	Medium truck	Heavy truck	Light bus	Heavy bus	Heavy bus	Semi-trailer
Engine size	100 cc	1600 cc	2300 cc	1300 cc	120 hp	120 hp	1300 cc	90 hp	140 hp	-
Bench mark speed (kph)	72	80	80	72	72	72	72	80	80	72
Lifetime average speed (kph)	56									
Life (years)	6	10	14	10	13	12	7	9	9	12
Annual mileage (km)	13000	18000	20000	25000	40000	50000	35000	60000	80000	60000
Fuel consumption (km/L)	30.0	10.0	7.3	9.5	4.5	3.6	9.5	4.5	4.0	2.6
Fuel type	G.P	(1)	G.R	(2)	Diesel					
Oil consumption (km/L)	-	1000	770	770	450	450	770	450	450	450
Representative tyre size	250-18 4 ply	560-13 4 ply	750-16 6 ply	600-14 8 ply	825-20 12 ply	825-20 12 ply	600-14 8 ply	750-16 6 ply	(7)	825-20 12-ply
Number of tyres	2	4	4	4	6	10	4	6	6	14

Table 3 Summary of Data Used for Calcuting Vehicle Operating Costs (Continued)

Veh. class	1	2	3	4	5	6	7	8*	8	9
New tyre life(km)	30000	40000	50000	50000	50000	50000	50000	50000	50000	50000
Retread life(km)	-	32000	40000	40000	40000	40000	40000	40000	40000	40000
Number of retreads	-	0.5	0.5	0.5	1.0	1.5	0.5	1.0	1.5	1.5
Parts cost (3)	0.100	0.126	0.138	0.200	0.080	0.080	0.200	0.080	0.080	0.020
Labour cost (4)	0.80	1.65	1.90	1.90	5.80	9.40	1.90	5.50	6.50	8.70
Overhead (5)	0	0	0	0	5.0	5.0	0	5.0	7.3	(6)

*Heavy bus used for Ban Bung-Ban Khai feeder road only (90 hp engine)

(1) 45% Premium : 55% Regular

(2) 65% Petrol : 35% Diesel

(3) % of economic cost of vehicle per 1000 km

(4) Hours of labour per 1000 km

(5) Expressed as a percentage of the V.O.C. at average lifetime speed

(6) Equal to the actual value derived for heavy trucks

(7) 30% use 900-20,12 ply; 70% use 825-20,12 ply

Source: VALLENTINE, LAURIE & DAVIES (1976) Final Report on Investment Alternatives in Highways in the Corridors between Ban Bung and Ban Khai, Vol. II

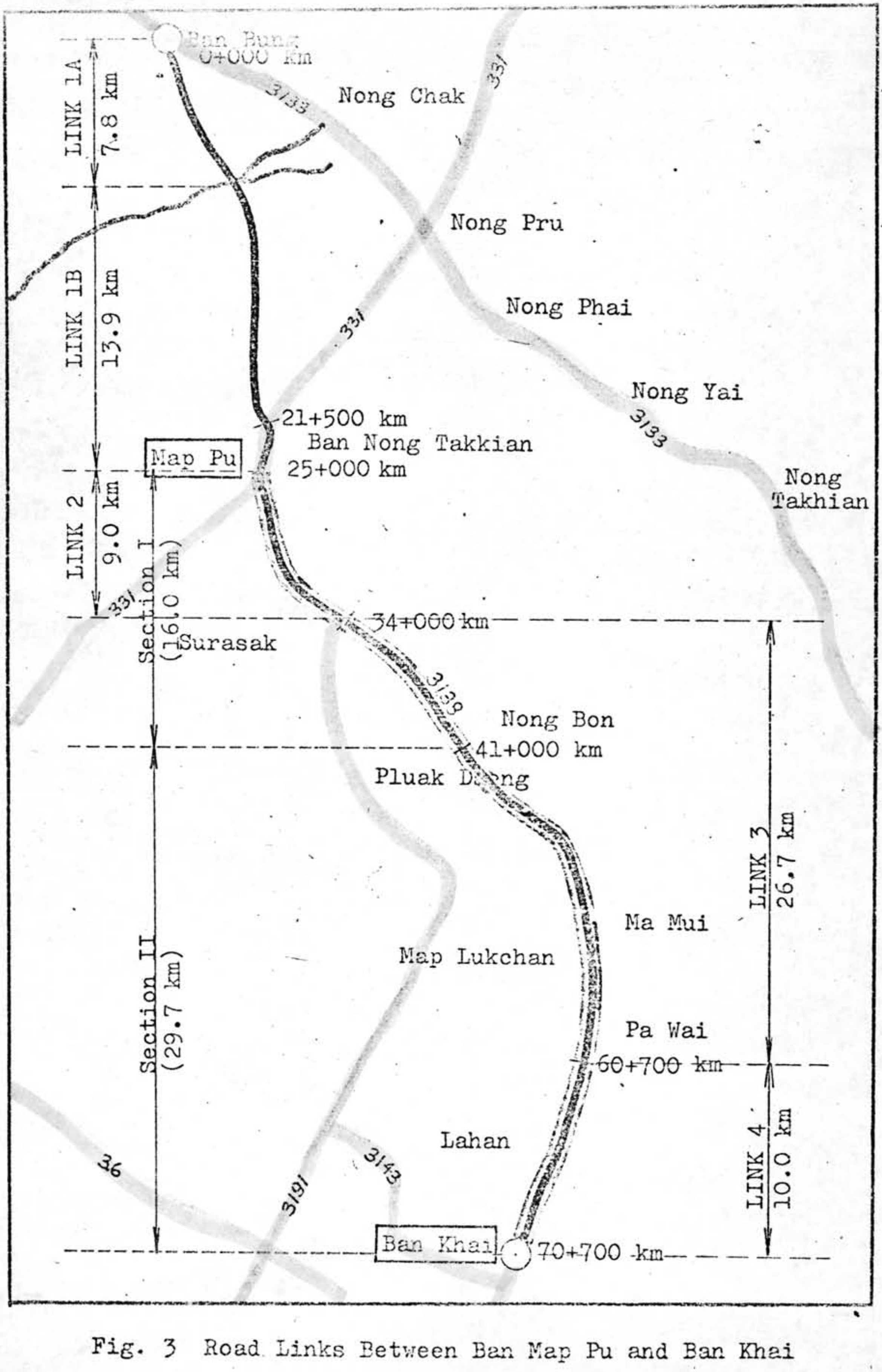


Fig. 3 Road Links Between Ban Map Pu and Ban Khai

Table 4 DEPARTMENT OF HIGHWAYS: Feeder Road Standards

Road Class		F_1	F_2	F_3
ADT		4,000-8,000	2,000-4,000	1,000-2,000
Design Speed (kph)	Flat-Rolling terrain	70-90	70-90	70-90
	Hilly terrain	55-70	55-70	55-70
	Mountainous terrain	40-55	40-55	40-55
Maximum Gradient (%)	Flat-Rolling terrain	6	6	6
	Hilly terrain	8	8	8
	Mountainous terrain	10	10	10
Width of (m)	Carriage-way	7	6.5	6.0
	Formation	12	11	10
	Shoulder	2.5	2.25	2

Source: From VALLENTINE, LAURIE & DAVIES (1976)

F_4: ADT 200-1,000, Max. Gradient 10%, 9-m travelled-way.

F_5: ADT Less than 200, Max. Gradient 12%, 8-m travelled-way.

be provided, the standard depending upon the Average Daily Traffic (ADT). The geometric standards are related to both ADT and type of terrain. The minimum width of bridges is 8 metres, and pavement design is based on equivalent standard axles. The road standards and pavement design thickness adopted for each link of the study road are shown in Table 5.

Table 5 Pavement Thickness of Ban Bung-Ban Khai Feeder Road

Item	Link 2 (9.0 km)			Link 3 (26.7 km)			Link 4
	2A	2B	2C	3A	3B	3C	
Length (km)	4.0	1.5	3.5	6.0	1.0	19.7	10.0
Geometric standard	F_2			F_3			F_2
Subgrade CBR %	5	10	20	5	10	20	20
Pavement type	Prime and double surface dressing						
Base (cm)	20.0	20.0	20.0	15.0	15.0	15.0	20.0
Subbase (cm)	10.0	6.0	-	10.0	10.0	-	-
Improved subgrade (cm)	10.0	-	-	9.0	-	-	-
Total (cm)	40.0	26.0	20.0	34.0	25.0	15.0	20.0

Traffic Forecasts

Growth rates have been developed by VALLENTINE, LAURIE & DAVIES (1976) separately for normal traffic, generated traffic, developmental traffic, diverted traffic, and special traffic. Normal traffic growth rates were further separated for four groups of vehicles: passenger cars, four-wheel drive vehicles, light trucks and light buses as group 1; motorcycles as group 2; medium and heavy trucks as group 3; and heavy buses as group 4. A uniform set of normal-traffic growth rates for each group of vehicles was developed for each link in the route. Generated traffic growth rates were used only for passenger cars because the growth rate for heavy vehicles (which would be the result of investment in new vehicles to cope with increasing production in the area) was so small that it could be ignored. A developmental traffic growth rate, which would occur on account of new areas of land being opened up and developed, was not used as there is substantially no new land available for development. Diverted traffic growth rates were assumed to be equal to those of the total traffic from which it was diverted. Special traffic growth was neglected as there was no information available on planned development. A summary of the traffic forecasts in terms of average daily traffic for each type of vehicle is shown in Table 6.

Table 6 Traffic Forecasts by Vehicle Class (ADT)

Year	Vehicle Class									Total
	MC	PC	4-W	LT	MT	HT	LB	HB	ST	
Link 2 (9.0 km)										
1973	110	10	43	100	146	54	10	44	0	517
1979	279	30	77	195	237	92	17	110	0	1037
1984	373	411	27	150	285	157	27	148	2	1580
1989	472	680	38	228	336	245	41	198	2	2240
1993	558	974	50	319	373	340	58	248	3	2923
2003	749	1875	97	613	667	608	112	435	4	5160
Link 3 (26.7 km)										
1973	75	4	5	18	22	6	11	25	0	166
1979	316	24	16	76	64	24	27	108	0	655
1984	398	222	17	56	75	44	43	146	2	1003
1989	422	451	24	86	89	69	66	195	2	1424
1993	447	713	32	119	97	95	93	245	2	1843
2003	600	1370	61	227	173	169	179	429	2	3210
Link 4 (10.0 km)										
1973	421	2	18	103	93	43	52	10	0	742
1979	1126	20	39	225	169	83	97	82	0	1841
1984	1433	600	52	173	209	133	151	111	2	2864
1989	1590	1306	74	265	255	198	232	150	2	4072
1993	1595	2126	96	371	292	267	326	189	3	5265
2003	2142	4100	187	712	522	477	629	333	4	9106

Source: VALLENTINE, LAURIE & DAVIES (1976)

Equivalent Standard Axles

Vehicle weight statistics obtained by VALLENTINE, LAURIE & DAVIES (1976) from origin-destination (O-D) surveys, weighbridge stations and sugar refinery records were converted into axle loads and these in turn were converted to equivalent 8,200-kg standard axle loads. This was done for each vehicle by determining the total average weights, both laden and unladen, from the data. These weights were distributed over the axles depending on the vehicle geometry; each axle load was converted into standard axles and then totalled to give the equivalent standard axle load for the vehicle. Finally, the average equivalent standard axle load for each vehicle class was determined from the percentages of vehicles in the traffic travelling laden and unladen. The average equivalent standard axle load of each vehicle class calculated on this basis resulted in the coefficients shown in Table 7.

Table 7 Average Equivalent Standard Axles by Vehicle Class

Vehicle Class	Average Equivalent Standard Axle Load
MC	0
PC	0
4-W	0.0001
LT	0.0003
MT	0.6486
HT	0.6462
LB	0.0002
HB	0.0420
ST	1.7431

Design Considerations

All the design items are referred to those proposed by VALLENTINE, LAURIE & DAVIES (1976) for Ban Bung-Ban Khai feeder road.

Geometric design

For the roadway designed, grades do not exceed 7 percent and all horizontal curves have radii in excess of 300 metres. The minimum length of vertical curve is 120 metres.

Earthwork design

Because there is an absence of deep cuts or high fills, the foundation conditions for all embankments are more than adequate. The earthwork cut slopes have been taken as 1:1, and side slopes of 1.5:1 for all fills. No stability problems were expected to occur along the route. The typical roadway cross-section is shown in Fig. 4.

Drainage design

Two methods of estimating discharge, as described in Drainage Design Analysis by THAILAND DEPARTMENT OF HIGHWAYS, have been employed. For catchment areas under 25 square kilometres, rainfall intensity values for a 10-year return period were used; for those greater than 25 square kilometres, a 20-

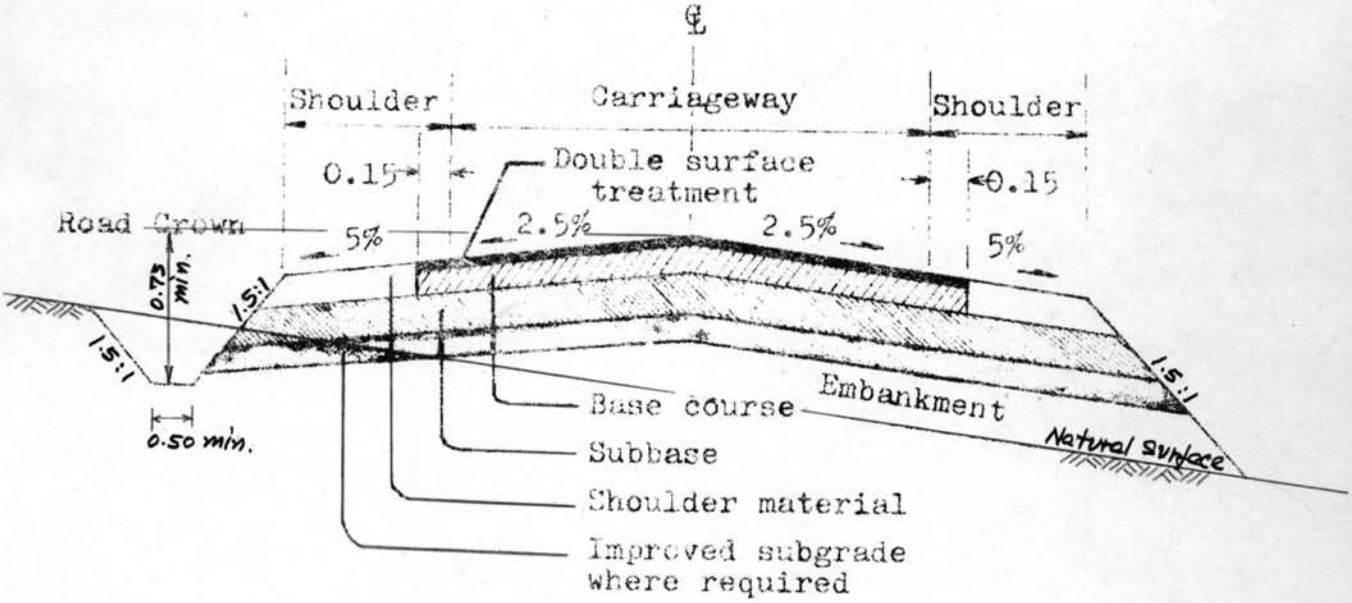


Fig. 4 Typical Roadway Section

year return period value of rainfall intensity was used. The design discharge capacity of a culvert pipe or box culvert was based on the theory of critical flow when the head water level is at the crown of the culvert at the entrance.

The waterway openings for bridges were determined by Manning's formula with bank slopes at 2:1, with the slope of the waterway estimated from a map, and n values selected from the range from 0.05 to 0.10. The structural design of bridges and culverts was in accordance with the <u>Standard Specifications for Highway Bridges</u> (AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS) with live loading of Class HS20-44.

Pavement design

Pavement design calculations were carried out by VALLENTINE, LAURIE & DAVIES (1976) for each road link and for each subgrade type within each road link. The design was based upon the number of equivalent standard axle loads (8,200 kg) which were estimated to pass over the segment of road during its design life. For design traffic loadings less than one-million ESA (Equivalent Standard Axles), a flexible pavement with a double bituminous surface treatment was adopted. The actual axle loads of the representative types of vehicles, loaded to the average values as determined from the O-D survey data, were converted to equivalent standard axles as described in a previous section.

Description of Input Data

In order to have the minimum number of computer runs, compatible with the aims of the present research, the Ban Map Pu-Ban Khai feeder road was divided into two sections. The first section started at chainage 25+000 km and ran to chainage 41+000 km; the second section started at chainage 41+000 km and ran to 70+700 km. These groupings would have important effects on the constraints of the RTIM Model, therefore adjustments and approximations were made as described in the following sections.

Alignment

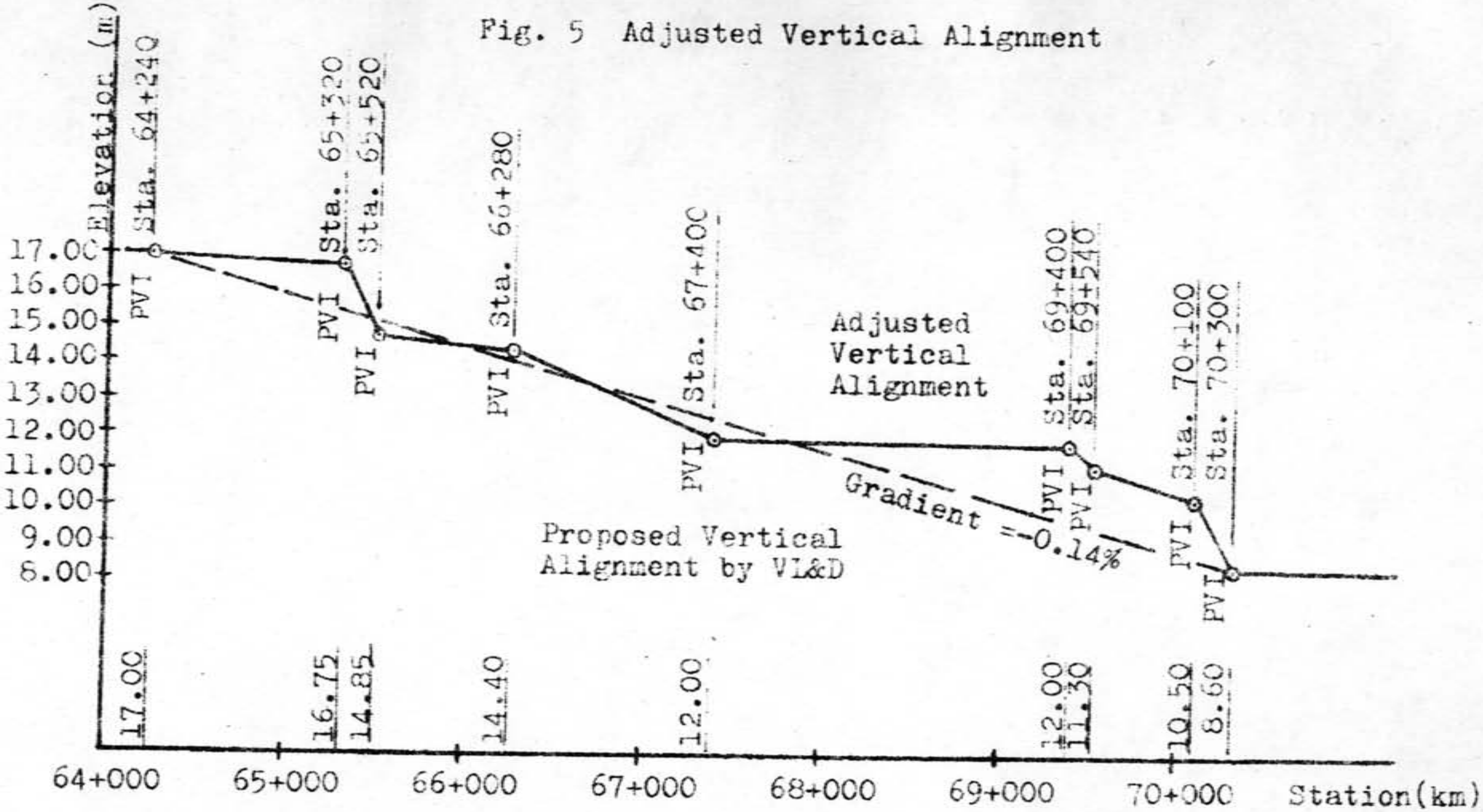
The horizontal alignment was put in the Model in terms of an average degree of curvature per kilometre ie, the summation of the absolute values of the deflection angles of all horizontal curves in the section divided by the length in kilometres of that section.

The constraint of the Model on vertical curves is that no more than 48 vertical curves can be entered in one run of the program. There were 94 vertical curves in the design by VALLENTINE, LAURIE & DAVIES (1976) for the vertical alignment between Ban Map Pu and Ban Khai. Section I had 39 vertical curves, which number did not exceed the constraint of the Model and could be possibly accepted in one computer run. Section II had 55 vertical curves which exceeded the constraint of the Model; if no adjustment were made, all the vertical alignment data of this section could not be put in the Model within one computer run. In order to have only one computer run for section II, it was decided to reduce the number of vertical curves if this could be done without violating the geometric design standard. By careful examination of the existing ground profile in the plan-profile (VALLENTINE, LAURIE & DAVIES, 1976), a length between chainage 64+240 km and chainage 70+300 km was found in which the existing ground profile was relatively flat. Thus, it was practicable to use a constant profile gradient between these two chainages. The result of this adjustment, as shown in Fig. 5 eliminated 7 vertical curves and reduced the total number of vertical curves to 48 curves which could be entered within one computer run. Data for the vertical alignment were put into the Model in terms of intersection-point chainage, intersection-point elevation, and curve length for each vertical curve.

Pavement layer thickness

The RTIM Model is limited to only one type of pavement surface and one roadway design for any one computer run. To use only two study sections, the constraints of the Model required that certain approximations be made.

Fig. 5 Adjusted Vertical Alignment



Proposed Vertical Alignment			Adjusted Vertical Alignment		
Station (km)	Elevation (m)	Length of curve (m)	Station (km)	Elevation (m)	Length of curve (m)
64+240	17.00	200	64+200	17.00	200
65+320	16.75	200			
65+520	14.80	200			
66+280	14.40	300			
67+400	12.00	300			
69+400	12.00	140			
69+540	11.30	140			
70+100	10.50	200			
70+300	8.60	200	70+300	8.60	200

In Section I, which consisted of Link 2 (9.0 km) and part of Link 3 (7.0 km), the choice of roadway standard was weighted by the longer length of Link 2 which was feeder road class F_2. This design was used for Section I in its entirety. For Section II, which consisted of the remainder of Link 3 (19.7 km) and all of Link 4 (10.0 km), the roadway standard for Link 3 (feeder road class F_3) was used.

Three types of pavement were designed by VALLENTINE, LAURIES & DAVIES (1976) for each of Links 2 and 3. It was necessary to select a single type of surface pavement for each section but a constraint imposed on this study was that costs conform to those of the VL&D analysis for subsequent comparison. Because the Model itself would calculate the quantities of material required for each pavement layer, these would differ from the designers' quantities. Thus, the cost of materials shown in the output of the Model would be wrong. In order to make use of the combination of several types of pavement surface in each section, the quantities of material in each pavement layer were estimated for each type of pavement, and summations were made of the same types of materials. The total quantity of each type of material used in the section was divided by the length and the width of road in that section. The result was a weighted equivalent thickness of each pavement layer for that section. These quantities were used as input data as shown in Table 8.

Table 8 Alignment and Construction Data

Item			Section I	Section II
Station		km	25+000 41+000	41+000 70+700
Construction time		year	2	
Analysis period		year	15	
Discount rate		%	12	
Maximum gradient		%	7	
Design speed		kph	80	
Minimum length of vertical curve		m	120	
Slope stability			0.5	
Soil characteristic	Cut material as embankment		Suitable	
	Bulking factor		1.25	
	Compaction factor		0.8	
	CBR of subgrade	%	9.06*	20.0
Road standard			F_2	F_3
Degree of curvature per kilometre			16.85	8.61
Road cross-section	Width of carriageway	m	6.5	6.0
	Carriageway crossfall	V:H	1:40	1:40
	Width of each shoulder	m	2.25	2.0
	Shoulder crossfall	V:H	1:20	1:20
	Cut slope	V:H	1:1	1:1
	Fill slope	V:H	1:1.5	1:1.5
Ditch	Depth	m	0.556	0.575
	Bottom width	m	0.50	0.50
	Bottom slope	V:H	0	0
	Side slope	V:H	1:1.5	1:1.5
Width of the strip to be cleared		m	14.0*	13.0*
Pavement thickness	Improved subgrade	mm	56.0*	0
	Subbase	mm	71.0*	0
	Base	mm	173.0*	172.0*
	PDSD	mm	25.0	25.0
	Shoulder material	mm	323.7*	200.3*
Rainfall	Average annual rainfall	mm	2000	2000
	Maximum hourly rainfall	mm	60	60
Extension of pipe beyond shoulder		m	3.5	3.5

*Adjusted value

The subgrade CBR value used for each section was also determined as a single average value weighted by the length of each sub-link in the section.

Drainage

The Model designs pipe culverts for the minor river crossing by using a formula built into the program. The designed section and number of pipes used are shown in the output print. The maximum number of minor river crossings that can be put into a single run of the program is 10. This limitation of the Model introduces considerable inflexibility in its use. Most of the rural roads in Thailand require that many minor drainage structures (pipes or box culverts) be provided for streams and minor rivers. The drainage designed by VALLENTINE, LAURIE & DAVIES (1976) between Ban Map Pu and Ban Khai amounts to about 70 minor stream crossings. This would require seven computer runs to satisfy the drainage constraint of the Model. Because there is a lack of information about the characteristics of the existing streams crossed by the Ban Map Pu-Ban Khai feeder road, and because it was intended to use only one computer run for each section, this part of program was not used. The Model enables the user to put in the total cost of bridges for major river crossings, so this capability was also used for the estimated cost of pipes and box culverts. The cost of pipes and box culverts for each section was calculated and put into the Model by adding to the cost of bridges.

Traffic

Traffic forecasts by VALLENTINE, LAURIE & DAVIES (1976) were made for each link as shown in Table 6. Link 2 and Link 3 were combined for Section I, and Link 3 and Link 4 were combined for Section II. Adjustment of the traffic volume used for each section was made by weighting the traffic volumes of each link by the portion of length of the link used in the section. Linear interpolations between the traffic forecast years were made to determine the annual traffic as shown in Table 9. These values were used as annual traffic inputs. The RTIM Model specifies eight types of vehicles:

Vehicle type 1 passenger cars

Vehicle type 2 light commercial vehicles

Vehicle type 3 heavy buses

Vehicle type 4 heavy commercial vehicles A (2-axle truck)

Vehicle type 5 heavy commercial vehicles B (3-axle truck)

Vehicle type 6 heavy commercial vehicles C (4-axle truck)

Vehicle type 7 heavy commercial vehicles D (5-axle truck)

Vehicle type 8 heavy commercial vehicles E (6-axle truck)

There are certain parameters which are fixed in the Model in consequence of types of vehicle shown above. Therefore, there is no capability for the user to specify his own series of vehi-

Table 9 Computed Traffic Volume (ADT)

Year	PC+ 4-W	LT+ LB	HB	MT	HT	ST	Total
Link 2ABC-3AB (16.0 km)							
1979	78	164	109	161	62	0	574
1980	132	160	117	168	71	0	648
1981	187	155	124	174	80	0	720
1982	241	151	132	181	89	0	794
1983	296	147	139	187	98	0	867
1984	351	143	147	193	107	2	943
1985	403	158	157	200	120	2	1040
1986	455	172	167	207	132	2	1135
1987	507	188	177	214	144	2	1232
1988	560	202	187	221	156	2	1328
1989	612	218	197	228	168	2	1425
1990	684	239	209	234	184	2	1552
1991	757	260	222	240	200	2	1681
1992	829	283	234	246	216	3	1811
1993	902	304	247	252	233	3	1941
Link 3C-4 (29.7 km)							
1979	46	176	99	99	44	0	464
1980	113	176	106	103	50	0	548
1981	179	176	113	107	56	0	631
1982	245	176	120	112	62	0	715
1983	311	175	127	116	68	0	797
1984	378	174	134	120	74	2	882
1985	458	193	143	125	82	2	1003
1986	538	212	153	130	89	2	1124
1987	619	231	161	135	97	2	1245
1988	699	249	170	140	105	2	1365
1989	780	268	180	145	112	2	1487
1990	895	294	191	149	122	2	1653
1991	1011	321	203	154	132	2	1823
1992	1126	348	214	158	142	2	1990
1993	1242	375	226	163	153	2	2161

cle types. VALLENTINE, LAURIE & DAVIES (1976) adopted nine type of vehicles in their study of the Ban Bung-Ban Khai feeder road. Adjustments were made by combining the ADT-values of groups of vehicles having approximately the same engine capacities. Also, representative vehicle types to be used for the present study were selected with consideration of which types of vehicles had the greater amount of traffic volume. The six vehicle types finally selected for input to the Model are shown in Table 10.

Table 10 Representative Types of Vehicles Used in the Model

Vehicle Type	Group of the Same Capacity Range of Engine	Representative Type as Input Data
1	Passenger car, 4-wheel drive vehicle	Passenger car
2	Light truck Light bus	Light truck
3	Heavy bus	Heavy bus
4	Medium truck	Medium truck
5	Heavy truck	Heavy truck
6	Semi-trailer	Semi-trailer

Note: Motorcycles were not included in this analysis as they have a low operating cost and substantially no effect on pavement deterioration.

Ground data

The Model requires that there be at least one terrain cross-section for every 120 metres; the maximum number of cross-sections that can be put into one computer run is 500. The length of Ban Map Pu to Ban Khai feeder road is 45.7 kilometres; by using 100-metre intervals for the terrain cross-sections, the total number of cross-sections in Section I was 161 and the total number of cross-sections in Section II was 298. Each cross-section was put into the Model in terms of chainage, right and left offsets which were measured from the centre line of the road, and the elevation of each of the two offsets. In the present study, the ground data were obtained from the plan-profile sheets of VALLENTINE, LAURIE & DAVIES (1976). The offset points were selected within the right of way of the road. The offset distances were measured directly and then the elevation of each offset was interpolated between the existing ground contours.

Construction unit costs

VALLENTINE, LAURIE & DAVIES (1976) estimated the construction cost of the Ban Bung-Ban Khai feeder road based on the August 1974 unit rates, and two additions were made. The first addition was an increase of 8 percent of construction costs to allow for the minor items often omitted; the second addition was an increase of 11 percent of estimated construction costs to allow for the general costs of design and supervision in Thailand. Finally, the cost of land acquisition was added to obtain the total estimated construction costs as shown in Table 11.

The Model required the input data of miscellaneous costs as currency and the input data of overheads and supervision

Table 11 Total Construction Cost of Ban Bung-Ban Khai Feeder Road Estimated by VL&D (1976), Baht

Item	Unit	Financial Rate ฿	% Tax	Economic Rate ฿	Quantity	Economic Cost ฿
Clearing and grubbing	Ha	6,000	9.1	5,454.0	90	490,860
Excavation in rock	m^3	90	13.7	-	-	-
Excavation in soil	m^3	20	9.9	18.02	355,000	6,397,100
Embankment	m^3	56	9.6	50.62	435,000	22,021,440
Pipe culverts (0.8 m)	m	700	8.2	642.6	850	546,210
Pipe culverts (1.0 m)	m	1,350	8.7	1,232.5	1,320	1,626,966
Box culverts (large)	m^3	1,500	10.8	1,338.0	1,038	1,388,844
Box culverts (small)	m^3	1,900	10.0	1,710.0	1,034	1,768,140
Bridges (8-m wide)	m	36,000	11.3	31,932.0	394	12,581,208
Subbase and shoulder	m^3	100	10.8	89.2	64,350	5,740,020
Base course	m^3	240	6.7	223.9	74,750	16,738,020
Prime and double surface dressing	m^2	35	5.5	33.07	453,100	14,986,283
Bituminous conc. (0.05-m thick)	m^2	72	6.9	67.03	-	-

		84,285,091
Minor items 8%	(9.0% tax included) =	+6,742,807
		91,027,898
Design and supervision 11%	(2.2% tax included) =	+10,725,875
Land acquisition	=	+ 5,468,400
	Total construction cost =	107,222,173

costs as a percentage of the total construction cost, so it was necessary to calculate the approximate construction costs for Section I and Section II in order to obtain the costs of minor items. In the present study, approximation of costs by length of section was made for excavation, embankment and land acquisition; approximate costs by length and road standard used for the section were made for clearing and grubbing, subbase and shoulder, base course, and surface dressing; approximate costs, by computing the quantities used for the section from the drawings of VALLENTINE, LAURIE & DAVIES (1976), were obtained for all the drainage structures. Finally, the cost of land acquisition was added to the cost of minor items to be put into the Model. The approximate construction costs for Section I and Section II are shown in Table 12 and 13.

Vehicle operation and road maintenance

The vehicle operating cost data were mainly obtained from VALLENTINE, LAURIE & DAVIES (1976), except for the standing cost. The annual crew hours were obtained from the default options of the Model. The crew time cost and the passenger or cargo time cost were obtained from SINTHUSARN (1976) as shown in Table 14.

Because there was a lack of reliable information regarding standardized maintenance packages suitable for rural roads in Thailand, the present study took advantage of the road main-

Table 12 Estimated Construction Cost of Section I by Approximation, Baht

Item	Link 2			Link 3		Section I
	2A	2B	2C	3A	3B	2ABC+3AB
Length in km	4.0	1.5	3.5	6.0	1.0	16.0
Clearing and grubbing	30,542	11,453	26,724	42,541	7,090	118,350
Excavation in soil	389,473	146,052	340,789	584,210	97,368	1,557,892
Embankment	1,340,621	502,733	1,173,043	2,010,931	335,155	5,362,483
Pipe culverts (0.8 m)	46,267	34,700	-	11,567	-	92,534
Pipe culverts (1.0 m)	136,807	-	68,404	205,211	-	410,422
Box culverts (large)	-	-	242,766	-	-	242,766
Box culverts (small)	-	138,510	-	132,969	-	271,479
Bridges (8-m wide)	-	-	-	1,405,008	638,640	2,043,648
Subbase and shoulder	761,768	222,286	299,712	906,361	151,015	2,341,142
Base course	1,164,280	436,605	1,018,745	1,209,060	201,510	4,030,200
Prime and double surface dressing	939,188	352,195	821,789	1,309,572	218,262	3,641,006

		20,111,922
Minor items 8%	=	+1,608,954
Land acquisition	=	+1,331,726
		23,052,602
Design and supervision 11%	=	+2,535,786
Total construction cost	=	25,588,386

Table 13 Estimated Construction Cost of Section II by Approximation, Baht

Item	Link 3 3C	Link 4	Section II 3C+4
Length in km	19.7	10.0	29.7
Clearing and grubbing	139,677	76,356	216,033
Excavation in soil	1,918,156	973,683	2,891,839
Embankment	6,602,558	3,351,552	9,954,110
Pipe culverts (0.8 m)	231,336	138,801	370,137
Pipe culverts (1.0 m)	205,211	228,012	433,223
Box culverts (large)	433,512	-	433,512
Box culverts (small)	221,616	-	221,616
Bridges (8-m wide)	2,235,240	4,534,344	6,769,584
Subbase and shoulder	1,113,394	856,320	1,969,714
Base course	3,969,747	2,910,700	6,880,447
Prime and double surface dressing	4,299,761	2,347,970	6,647,731

		36,787,946
Minor items 8%	=	+2,943,036
Land acquisition	=	+2,472,016
		42,202,998
Design and supervision 11%	=	+4,642,330
Total construction cost	=	46,845,328

Table 14 Vehicle Operation Data

Item		PC	LT	HB	MT	HT	ST
Fuel type		petrol	petrol	diesel	diesel	diesel	diesel
Annual mileage	km	18,000	30,000	60,000	40,000	50,000	60,000
Annual crew hours (1)	hr	0	2,000	6,000	7,500	5,000	5,000
Brake horse power	HP	-	-	-	120	120	240
Unladen weight	tons	-	-	-	5.1	6.5	8.0
Average payload	tons	-	-	-	6.4	8.8	12.0
Vehicle cost	฿	75,900	57,200	172,500	205,190	236,650	1,294,000
Single tyre cost	฿	307	508	740	1,530	1,530	1,530
Crew time cost (2)	฿/hr	0	6	10	6	6	6
Standing cost (1)	%	10	25	25	25	25	25
Passenger or cargo time cost (2)	฿/hr	30	10	50	7	7	7

(1) From the default option of the Model
(2) From SINTHUSARN (1976)

Economic price of fuel:

Petrol	฿/L	2.13
Diesel	฿/L	1.91
Oil	฿/L	8.50
Labour cost	฿/hr	35.40

tenance package from the default option of the Model; all the unit rates were obtained from SINTHUSARN (1976) as shown in Table 15. The present study also used 11 percent of the maintenance cost to account for overheads and supervision. Overlay material of asphaltic concrete 0.05-m thick was put into the Model as a maintenance operation to serve for the control mode of the program.

Stage construction

The RTIM Model has the constraint of road deterioration in term of roughness for surface-dressed roads. This roughness, as calculated by the Model, would be the major cause of the termination of the program if there were no initial check on certain parameters before the application of the input data to the Model. It was found that the traffic volumes travelling along the study section were not within the range that would be suitable for upgrading from the initially selected gravel road or unpaved road to a bituminous road or paved road; this effect will be discussed in the last chapter. So, the present study made no use of the stage construction options of the Model.

Table 15 Unit Rates for the Maintenance Package of the Model

4500-litre capacity self-propelled liquid bitumen distributor	B/hr	110.0
0.25-tonne hand-operated vibrating roller	B/hr	20.0
Motor grader with a 3.7-metre blade	B/hr	110.0
10-tonne self-propelled roller	B/hr	45.0
Tractor-mower combination with a 1.8-metre sweep	B/hr	50.0
Self-propelled water tank with six cubic metre capacity	B/hr	67.5
Four-cubic metre capacity tipper truck	B/hr	67.5
Liquid bitumen source cost loaded in the distributor	B/L	1.5
Surface dressing stone source cost loaded on truck	B/m^3	132.0
Base patch material cost on site	B/m^3	132.0
Surface patch mix cost on site	B/m^3	350.0
Gravel source cost loaded on truck	B/m^3	0
Water source cost loaded in tanker	B/m^3	0
Diesel fuel cost delivered to the maintenance depot	B/L	1.0

Labourer	B/hr	4.0
Truck driver	B/hr	5.0
Plant operator	B/hr	8.0
Foreman	B/hr	10.0