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THE KINGDOM OF THAILAND

BANGKOK METROPOLITAN ADMINISTRATION

STUDY ON ROAD IMPROVEMENT, REHABILITATION AND TRAFFIC SAFETY IN BANGKOK

FINAL REPORT

SUMMARY

MARCH 1987

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

It is with great pleasure that I present this report entitled a Study on Road Improvement, Rehabilitation and Traffic Safety in Bangkok to the Government of the Kingdom of Thailand.

This report embodies the result of a study which was carried out (in Bangkok Metropolitan area) from June, 1985 to March, 1987 by a Japanese study team commissioned by the Japan International Cooperation Agency following the request of the Government of the Kingdom of Thailand to the Government of Japan.

The study team, headed by Mr. Nobuichi Nomoto (from June, 1985 to September, 1985) and Mr. Takenori Harikai (from September, 1985 to March, 1987), had a series of close discussions with the officials concerned of the Government of Thailand and conducted a wide scope of field survey.

I sincerely hope that this report will be useful as a basic reference for development of the region.

I am particularly pleased to express my appreciation to the officials concerned of the Government of the Kingdom of Thailand for their close cooperation extended to the Japanese team.

March, 1987

Keisuke Arita
President

Japan International Cooperation Agency

LETTER OF TRANSMITTAL

March, 1987

His Excellency Mr. Keisuke Arita
President
The Japan International Cooperation Agency
Shinjuku Mitsui Building
Nishi Shinjuku 2-1
Shinjuku-ku, Tokyo
Japan

Dear Mr. President:

It is my great pleasure to submit herewith the Report of the Study on Road Improvement, Rehabilitation and Traffic Safety in Bangkok, in the Kingdom of Thailand.

This report is the result of studies carried out by the Study Team consisting of the International Engineering Consultants Association of Japan. During the service period, the Study Team conducted the road and traffic surveys for the urban road network in the Study Area encircled by the Middle Ring Road in Bangkok with the total road length of 350 km, and prepared 1) a pilot road inventory system for 2 districts of Bangkok with system and operation manuals, 2) 10 road improvement plans at the critically congested intersections with related technical guideline, 3) 5 pavement rehabilitation plans for the road sections selected from 111 surveyed sections with related technical guideline, 4) 10 traffic safety plans for the selected hazardous road sections with related technical guideline, and 5) a review on BMA road organization.

The Study Team has completed the above service with a firm belief that implementation of above plans will substantially contribute to the improvement of the very serious road traffic problems in Bangkok, in particular the heavy traffic congestion and frequent occurrence of traffic accidents.

On behalf of the Study Team, I wish to express herewith our sincere appreciation to the officials concerned of the Bangkok Metropolitan Administration and the Government of the Kingdom of Thailand for the effective cooperation, assistance and warm hospitality extended to us during our stay in Bangkok, Thailand.

Our gratitudes are also due to the Japan International Cooperation Agency and the JICA Advisory Committee for their valuable advice and support during the studies and preparation of this report.

Yours sincerely,

Takenori Harikai

Takenori Harikai
Leader, Study Team
Study on Road Improvement, Rehabilitation
and Traffic Safety in Bangkok
(International Engineering Consultants Association)

STUDY ON ROAD IMPROVEMENT, REHABILITATION AND TRAFFIC SAFETY IN BANGKOK

FINAL REPORT

LIST OF ABBREVIATIONS

BMA	Bangkok Metropolitan Administration
CPD	City Planning Division, BMA
CMD	Construction and Maintenance Division, BMA
DD	Design Division, BMA
PPD	Policy and Planning Division, BMA
PPSd	Public Works Planning Sub-division, BMA
DPW	Department of Public Works, BMA
DDS	Department of Drainage and Sewerage, BMA
TED	Traffic Engineering Division, BMA
MOI	Ministry of Interior
OARD	Office of Accelerated Rural Development, MOI
OCMRT	Office of the Committee for the Management Road Traffic, MOI
OPP	Office of Policy and Planning, MOI
PWD	Public Works Department, MOI
TCPD	Town and Country Planning Department, MOI
TPD	Traffic Police Division, MOI
LDPD	License Division of Police Department, MOI
MOC	Ministry of Communications
DOH	Department of Highways, MOC
DLT	Department of Land Transport, MOC
ETA	Expressway and Rapid Transit Authority of Thailand
NESDB	National Economic and Social Development Board
SRT	State Railway of Thailand
MEA	Metropolitan Electricity Authority
AIT	Asia Institute of Technology
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
BS	British Standards
CAB	Cable Box
CBD	Central Business District
HCM	Highway Capacity Manual
MCI	Maintenance Control Index
MSL	Mean Sea Level
MTS	Mass Transit System
NECO	National Executive Council Order
PCU	Passenger Car Unit
PSI	Present Serviceablility Index
RAL	Richtlinien für die Anlage von Landstraßen
SSES	Second Stage Expressway System
STTR	Short Term Urban Transport Review

CONTENTS

1. INTRODUCTION

(1) Background

In the Bangkok Metropolitan area, the main transportation means both for passengers and goods are roads. In parallel with the expansion of social and economic activities, the number of vehicles registered in the area increased to some one million in 1983, outpacing the development of road facilities. This has resulted in a serious road traffic problem in the form of traffic congestion and frequent occurrences of accidents.

To cope with the ever growing traffic problem, it is required to make full use of the existing road systems together with large-scale road development projects. The BMA, thus, decided to employ the engineering and administrative experiences on urban roads in Japan who also has been exerting itself for the similar problems as faced in Bangkok.

The Government of Thailand, therefore, requested the Government of Japan for technical assistance to conduct a study on road improvement, pavement rehabilitation and traffic safety in Bangkok. The Japan International Cooperation Agency (JICA), the official agency responsible for implementation of technical cooperation programs of the Government of Japan, engaged the International Engineering Consultants Association (IECA) of Japan for consulting services to the study.

(2) Objectives of Study

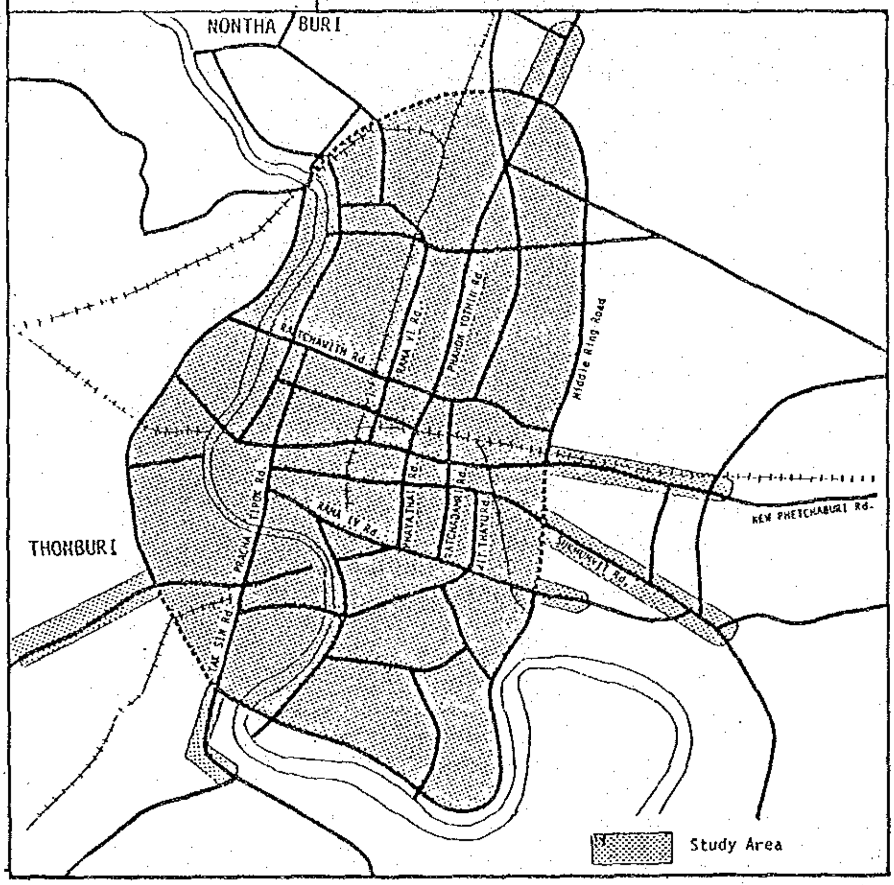
The main objectives of the study is to provide the BMA with engineering expertise and information necessary to the planning of road and pavement improvement and traffic safety measure, based on the findings of surveys and studies for the road network of total length of 350 km within a selected area (the area encircled by the middle ring road).

(3) Scope of Study

The study covers a wide range of road and traffic engineering fields as itemized below;

1) Traffic Survey	(traffic volume count, intersection traffic volume count, travel speed, congestion, motor vehicle O-D survey)
2) Road Inventory	(data base system, pilot road inventory)

Figure 1.1 Study Area



3) Road Improvement (bottleneck identification method, improvement plan);

4) Pavement Rehabilitation (pavement rating method, rehabilitation plan);

5) Traffic Safety (identification method of hazardous location, traffic safety plan);

6) Technical Guideline;

7) Review on BMA Road Organization.

2. TRAFFIC SURVEY

(1) Type of Survey

The following five kinds of traffic surveys were carried out in the study area;

1) Traffic volume survey

2) Intersection traffic volume survey

3) Travel speed survey

4) Traffic congestion survey

5) Motor vehicle O-D survey

(2) Traffic Volume Survey

The traffic volumes at 248 points on the study roads were obtained mainly by updating the traffic survey data conducted by OCMRT in the year 1984. The data updating was made based on the results of traffic volume survey at fifty stations in this study. Vehicular composition of the OCMRT traffic volume data, which have no classification of vehicle types, were also estimated applying the new traffic survey in this study.

The heaviest traffic volume is recorded on Vibhavadi-Rangsit Highway (80,000 - 90,000 veh/12h). Phahon Yothin Rd. also carries heavy traffic (about 55,000 veh/12h). Both roads connect the northern part of Bangkok with the central business district. The other major roads with traffic volumes more than 45,000 veh/12h are as follows:

Rama IV Rd.	53,000 - 74,000	Vibahavadi Rangsit Highway	80,000 - 90,000
Rama I Rd.	49,000	Phahon Yothin Rd.	46,000 - 56,000
Sukhumvit Rd.	46,000 - 48,000	Somdet Phra Chao Taksin Rd.	54,000 - 64,000
Petburi Rd.	46,000 - 80,000	Ratchadamnoen Klang	69,000 - 89,000
Phaya Thai Rd.	54,000	Asok-Din Daeng	47,000

As for vehicular composition, passenger cars account for approximately 45% in the northern and the eastern parts of the study area, about 30% in the southern part and 25% in the western part (Thonburi). The regional variations in vehicular composition are likely attributable to the features of their land use patterns.

Traffic conditions on a mid-block section (a road section between two adjacent intersections) can be represented by congestion degree which is defined as a ratio between peak hour traffic volume and design traffic capacity.

The congestion degree along two-third roads in length in the study area is less than 0.5, while only 2% of roads exceed 1.0. This figure indicates that most of the roads have traffic capacity sufficient enough to accommodate present traffic demands. In other words, this implicitly suggests that traffic jams observed here and there in Bangkok are mostly caused by traffic bottlenecks at intersections.

(3) Intersection Traffic Volume Survey

Traffic movements' data at intersections which hinder free flows of traffic are essential information for setting forth road improvement plans. The intersection traffic volume survey was carried out at forty six (46) major intersections. The survey counted the volumes of inflow traffic and their directional movements, i.e., left-turn, right-turn and straight.

Saturation degrees at the intersections were calculated by using the intersection traffic volume data and the result of studies on intersection's capacity conducted by OCMRT. At about 31% of intersections, the saturation degree exceeds 0.9 during peak hours. This suggests that major bottlenecks in traffic flows in Bangkok are at intersections.

(4) Travel Speed Survey

A travel speed on a road is a highly effective indicator to show the service level of the road. The fluctuations in travel speeds along a route generally agree with traffic conditions of roads in terms of traffic capacity, i.e., less speed at a under-capacity segment and higher speed at a favorable segment. Therefore, detailed analyses on travel speeds' data produce clues to identify potential bottlenecks of traffic. The travel speed survey by road section was conducted during morning and evening peak hours along twenty three major routes and its result was used to develop a road traffic rating system to identify traffic bottlenecks.

(5) Motor Vehicle O-D Survey

Traffic volume counts and intersection traffic volume surveys on individual roads are essential as a basis for traffic control and operation and other short-term objectives. However, they have limited values for long-term planning, since traffic will shift with improvements or changes in conditions. To grasp real traffic demands both quantitatively and qualitatively, a motor vehicle origin-destination (O-D) survey is an effective means.

1) Survey Method

The motor vehichle O-D survey in the study is composed of "Home Interview" and "Roadside Interview" on a sampling basis. The home interview was made with selected 31,000 vehicle owners inclusive of taxi in the study area. The sampling rate was 6.1% (to secure the survey result at 90% level of confidence, a sampling rate of 6% is required statistically). As for buses with fixed operation routes, O-D trip data were provided by the bus authority.

The roadside interview is necessary to obtain O-D data of vehicles which are registered outside the study area but travel into the study area. The result of the interview also is used to reconcile the home interview. The roadside interview was carried out at 17 stations where radial arterials intersect with the cordon line of the study area and 10 stations at on-ramps of the ETA expressway. About 8 percent of the vehicles passing the stations were stopped and their drivers were interviewed.

Since the O-D survey was conducted on a sampling basis, the survey results were expanded to obtain the total number of motor vehicle trip. Expansion factor of home interview was estimated from the number of all the registered vehicles and sample data, while that of roadside interview is estimated from traffic volumes at stations and the sample data.

In order to confirm the accuracy of the O-D survey, the expanded O-D trips supposed to cross the three screen lines were compared to the traffic volumes counted on the lines. The results are satisfactory with the comparison ratios ranging between 0.86 and 1.09.

The study area was divided into smaller zones totaling 58, while the whole outside area was divided into wider zones of only 28. These zones identify the locations of origin and destination of vehicular trips.

2) Information Item of Home Interview

The information items sought for through the home interview are 19 and major ones are as follows;

- occupation of vehicle owner,
- type of vehicle,
- frequency of vehicle use,
- origin - destination of trips,
- trip purpose,
- parking place,
- commodity type, and
- number of passenger.

For the roadside interview which had to be made with drivers in a short period of time, the information items were limited to minimum requirements to the study. Major items are;

- vehicular type,
- origin - destination of trips,
- trip purpose,
- commodity type, and
- number of passenger.

3) Trip Generation

Total number of vehicle trip movement in the study area was approximately 2.2 million vehicle/day (except motor-cycle). Among them, the internal trips were approximately 1.7 million, the external trips were 500,000, and the external-external trips were 53,000.

The vehicle trip generation/attraction by type of vehicle is as follows. Total trip generation in the study area in the year 1985 is approximately 1.9 million veh/day (except motorcycle), of which about 45% are passenger car, 21% pick up and heavy truck, and 34% other types.

Table 2.1 Vehicle Trip Generation and Attraction in 1985 (Study Area)

(Unit: Vehicle Trip/day)

Type of Vehicle	Trip Generation	Trip Attraction	Total
1. Passenger Car	850,800	888,800	1,739,600 (45.4%)
2. Pick-up & Heavy Truck	392,200	412,500	804,700 (21.0)
3. Taxi & Samlor	550,500	558,700	1,109,200 (29.0)
4. Mini Bus & Bus	87,300	88,600	175,900 (4.6)
5. Total	1,880,800	1,948,600	3,829,400 (100.0)

4) Brief Analyses of O-D Data

a) Trip by vehicular type

The average number of trip per vehicle for all the vehicular types is 4.23 per day with breakdown of 3.57 for passenger car, 2.86 for pick up, 2.82 for heavy truck and 35.01 for taxi.

b) Travel distance

Travel distance which is the total length of trips made by one vehicle in a day is about 35 km on average. Taxi has the longest trip distance of 235 km, followed by heavy track (33km) and passenger car (30 km).

c) Trip distribution

Trip distribution of vehicles is shown in Figure 2.1 by desire line charts. The two-directional movement between each pair of zone block is drawn by a straight line whose width is proportional to the number of trips between zone blocks. The desire lines are flows of traffic as they would proceed by the shortest distance between zones of origin and destination.

Strong desire lines are seen between zone block No.4 (Pathumwan & Bang-rak) and its surrounding zone blocks, i.e., No.1 (Pra Nakhon), No.3 (Phaya Thai), No.5 (Yan Nawa) and No.6 (Phra Khanong)

d) Trip purpose

Trip purposes are summarized in Figure 2.2. The figure shows a breakdown of all trips in a day. As seen, about 27% are to work and to school, 17% business, 16% private, and remaining 40% go-home. Among "To work", approximately 16% takes children to school first and proceeds to office.

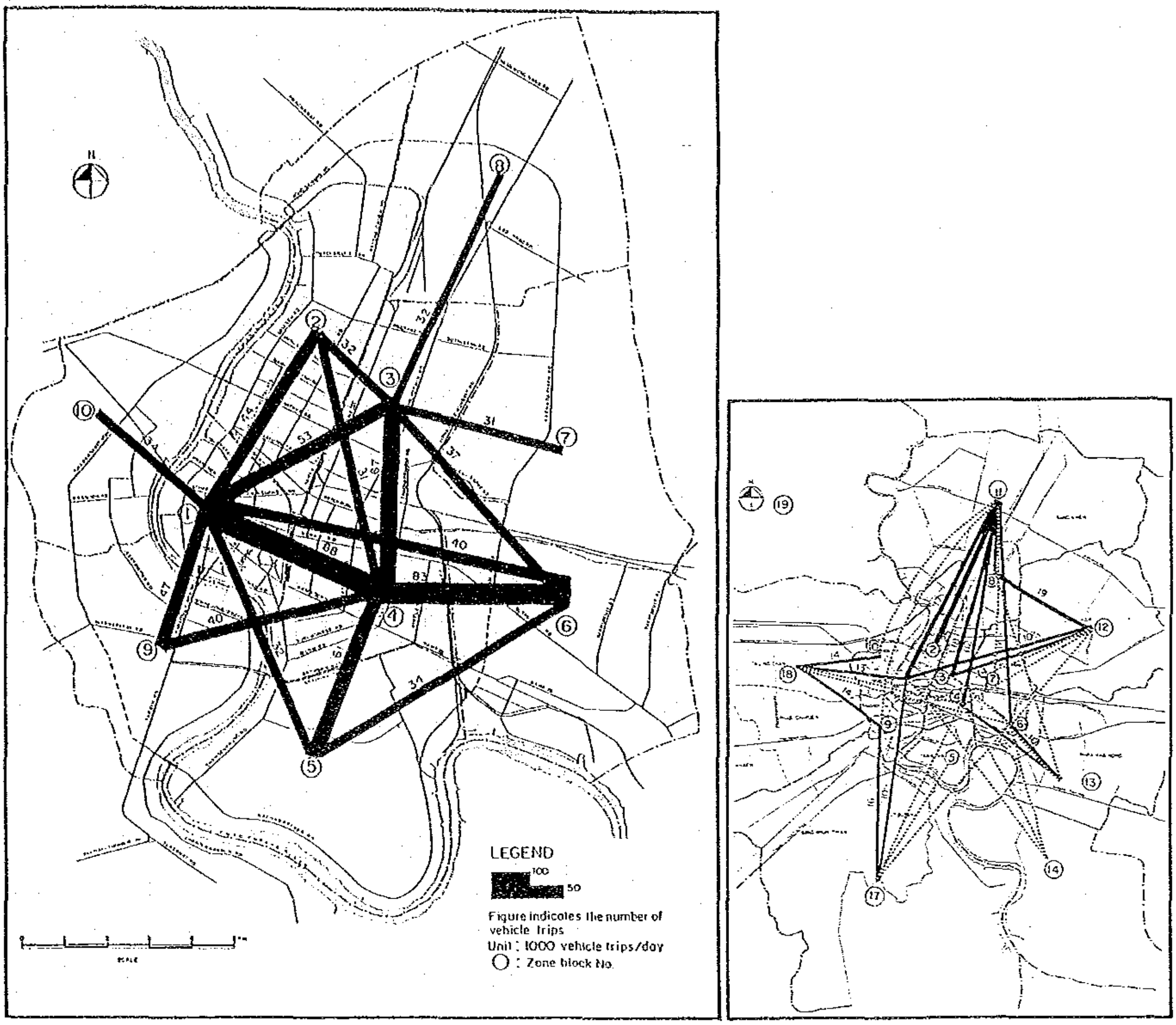


Figure 2.1 Desire Lines of Zone Trip

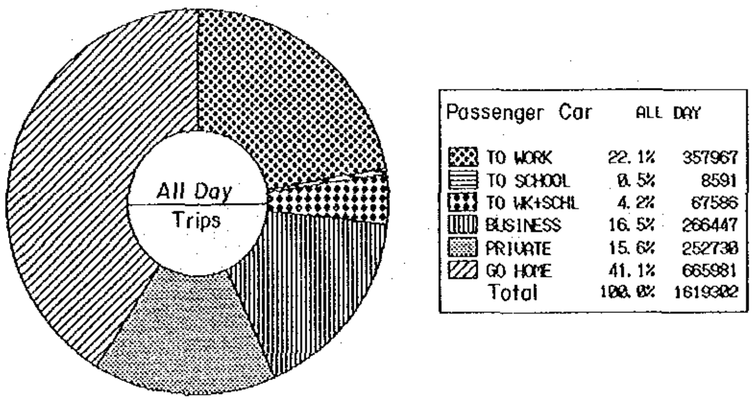


Figure 2.2 Trip Purposes (All Day)

(6) Data Files

The results of the traffic surveys in the study are stored in the following three master files for future analyses by the electronic computer:

a) Traffic master file for mid-block section
   - traffic volume data
   - travel speed data
   - traffic capacity
   - some of road inventory data

b) Traffic master file for intersection
   - turning movement data
   - queue length data
   - road inventory data
   - saturation flow rate

c) O-D master file

(7) Traffic Assignment

Vehicular trips obtained from the O-D survey were assigned by minimum time-route method in two cases of road networks, i.e., (1) present road network (2) future road network including roads under construction and concrete plans.

The O-D matrices of trips were divided into 4 lots (40%, 30%, 20% and 10%) for phasing assignments. Trip pairs in each lot are assigned on minimum time-routes which are determined by speed-flow curve according to accumulated assigned traffic volumes. Diversion to the ETA expressway was also taken into account by using the diversion model developed in the study.

(8) Road Categorization

1) Road function

The roads in a road network have their own functional features, no matter whether explicitly or implicitly. The roads in urban and suburban areas are broadly classified into four categories from the viewpoint of traffic features. They are major trunk road, major road, minor road and access road (in this study, access roads are excluded).

Planning and designing roads to adequate engineering standards in accordance with their functions are of a great importance to ensure smooth and safe traffic flows economically.

2) Categorization

Road function by traffic role can be decided according to the traffic characteristics, that is, traffic volume, trip length and volume of large commercial vehicles. Two attempts to categorize the roads in the study area were made applying the results of traffic assignment. One is by correlation between traffic volume and trip length. The other is by traffic volume and large commercial vehicles' volume.

The work of categorization by traffic volume and trip length are as follows;

a) to plot a traffic volume (x-axis) and average trip length (y-axis) on each road segment, and
b) to determine borderlines both for traffic and trip length. The borderlines divide road segments into 4 groups as illustrated below

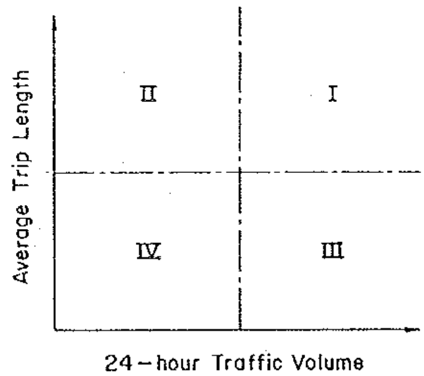


Figure 2.3 Categorization by Traffic Volume and Trip Length

The road segments in group 'I' with heavy traffic volume and long trip length could be assumed major trunk roads. And also, the group 'II' road segments with long trip length and relatively low traffic volume are classified into major trunk roads. The road segments of group 'III' with heavy traffic volume and relatively short trip length are defined as major roads. Those in group IV are minor roads.

The borderline for trip length (y-axis) has been set at 15 km, considering the inflectional point of the distribution of average trip length. For traffic volume, the capacity of 4-lane road for daily traffic volume (approximately 50,000 veh/day) has been assumed as borderline. The categorization by traffic volume and large commercial vehicles' volume also has been made in the same manner as the volume-trip length (in this case, to substitute trip length with large commercial vehicles' volume). The result is shown below.

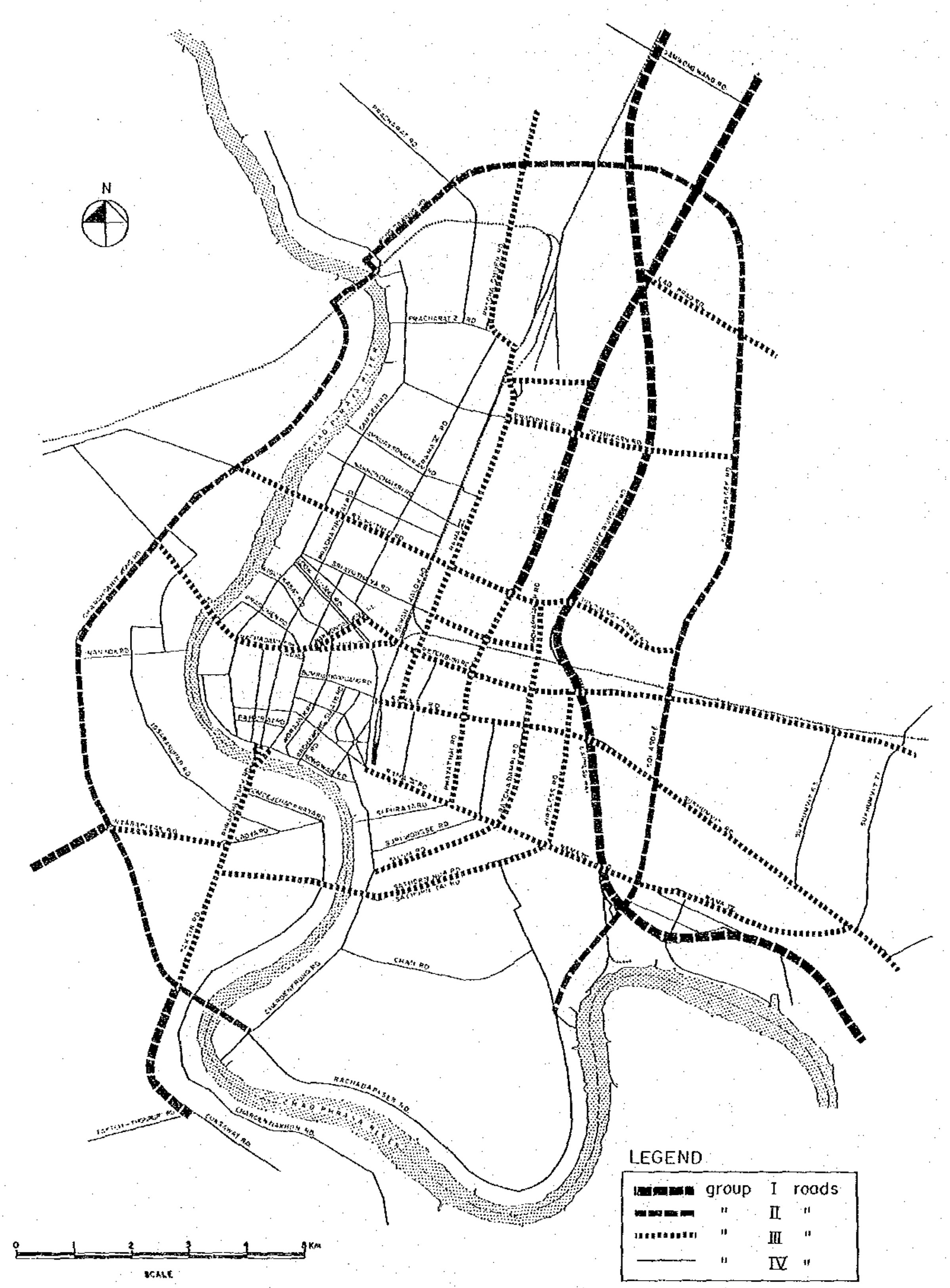


Figure 2.4 Road Categorization by Traffic Function

3. ROAD INVENTORY

(1) Scope of Study

A properly designed road inventory system enables road administrators to obtain readily necessary data and information on road and traffic conditions. This makes road administration works improve qualitatively and progress in economic benefit on road management. In this study, a road inventory system (METROS which stands for Metropolitan Road Inventory System) was developed with up-to-date electronic technics on a Relational Data Base Management System. Besides the system development, a pilot inventory data base for the roads in Pathumwan and Bangrak districts was established in order to demonstrate the application of the developed system.

(2) Control link and node system

To interlink the road data and traffic conditions with the locations of mid-block section of road, the road network has been subdivided into a number of control links with nodes at both ends of each link. The subdivision was made in such a way that characteristics of each control link could be assumed homogeneous in the light of engineering and administrative practices.

For a practical purpose, nodes in the data base system are divided into two, i.e. "Primary node" and "Secondary node". Primary nodes correspond to major intersections, while secondary nodes represent those which divide a mid-block section (a portion segmented by two adjacent intersections) into two or more control links as necessitated. The concept of control links and primary and secondary nodes is illustrated in Figure 3.1.

The number of control links for the road network in the study roads of 372 km, is in the order of 800.

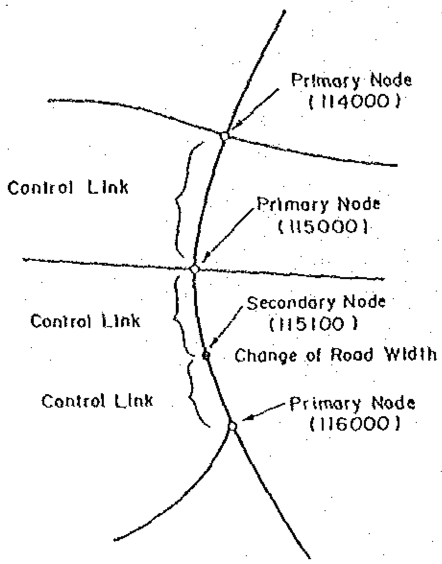


Figure 3.1 Illustration of Control Links and Nodes

(3) Data Base

Basic information of all the data items for road inventories is filed in the control link data base. However, for some data items such as bridge and pavement, more detailed information is often required to perform adequate management. Thus, following six data bases were developed. The data bases were designed to accommodate the contents and the number of data items indicated as follows;

- Control Link ; 84 items on geometric data, the number of lanes, the number of road facilities and its type, traffic data and traffic accident data etc.
- Bridge ; 27 items on structural type, span length, width, constructed year and conditions, etc.
- Pedestrian Bridge ; 23 items on similar contents to bridge,
- Pavement ; 23 items on pavement type, width and pavement area, constructed year, and conditions, etc,
- Public Utility ; 35 items on existence, location and type of water supply, electricity, telephane and drainage for road.
- Intersection ; 43 items on intersection type, regulation of turning, exixtence and arrangement of traffic signals, and queue length, etc.

(4) Hardware and Software

METROS can be operated with the following hardware environment.

Microprocessor system	:	NEC N5200/05MK II (768 KB)
Hard Disc Unit	:	NEC N5257-11 (20 KB)
Printer	:	NEC N5233-61 (Dot Matrix Printer)

This hardware system has a capacity sufficient enough to accommodate all data for the whole major roads in Bangkok.

METROS requires the following software environment.

Operating System	:	MS-DOS V2.11
Database Management System	:	dBASEII V2.4

METROS was designed by means of dBASE II which is the Relational Database Management System. MS-DOS is an operating system to load dBASE II.

(5) System

System flow of the road inventory is shown in Figure 3.2. Although dBASE II is capable of a wide variety of processing the inventory system, three interface programs for input, error - check and output were developed to make the operation of the road inventory system simple and handy and to protect the data bases from mishandling.

The input interface program is for appending new data, deleting obsolete data and altering data items.

The error - check interface program has been designed so as to indicate an appropriate error message when unsuitable data are input.

The output interface program consists of two components. One is for the prompt retrieval of frequent use data and outputting the data in standard forms. The other is outputting to recreate data bases as a protection means against possible unexpected erasure of data base due to mishandling.

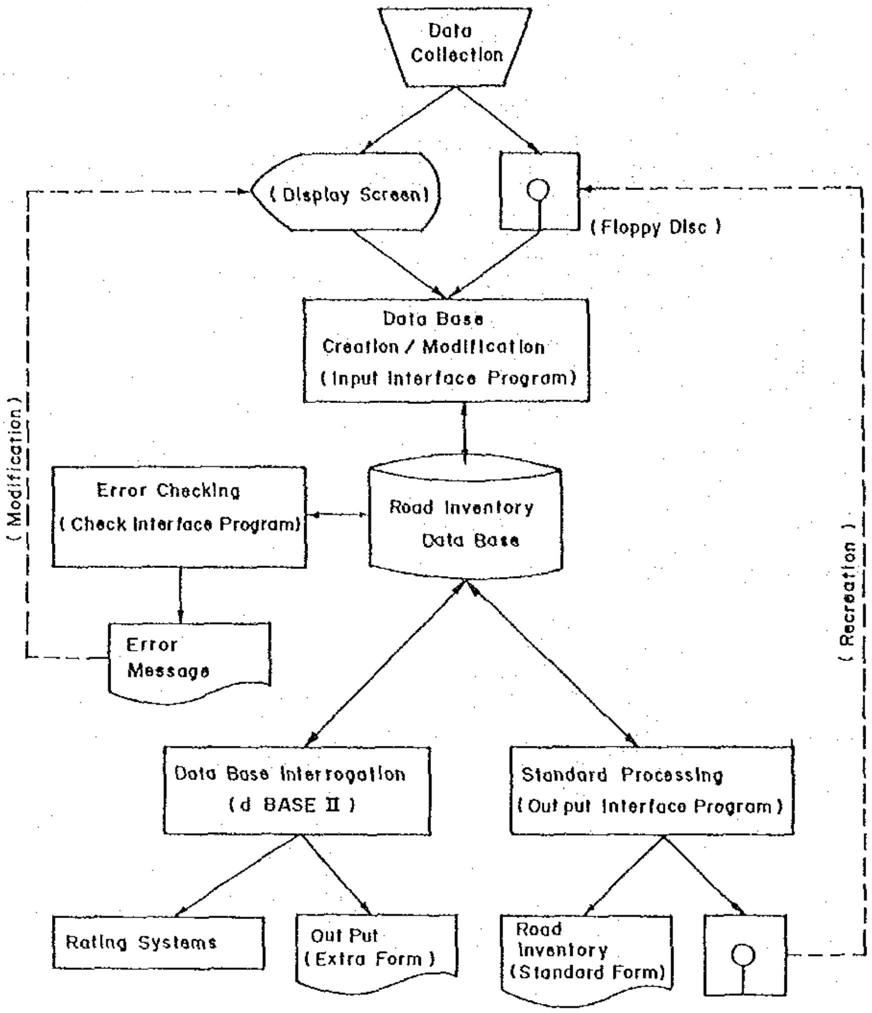


Figure 3.2 System Flow

(6) Manuals

To assist users of the road inventory system, the following manuals were prepared;

1) Users Manual
2) System Manual
3) dBASE II Manual
4) MS-DOS Manual
5) Operation Manual

(7) Pilot Road Inventory

In order to demonstrate the operation and to verify the functions of the developed inventory system, a pilot road inventory for the roads in Pathumwan and Bangrak districts with total road length of 35.2 km and 19.1 km, respectively, was established.

The number of control links and other major structures in the pilot area are as follows. No detail data of buried public utilities were available.

		Pathumwan district	Bangrak district
Control link	:	83	68
Node	:	43	40
Bridge	:	13	5
Pedestrian bridge	:	14	0
Total road length	:	35.2 km	19.1 km

4. ROAD IMPROVEMENT

(1) Scope of Study

The traffic problem in Bangkok could be solved by combination of a wide variety of approaches such as new road construction, improvement of existing roads and introduction of adequate traffic management. This study aims at providing the BMA with basic information which is necessary to make proper improvement plans of the existing roads.

The first step in preparing road improvement plans is to identify traffic bottlenecks on roads and then to plan remedial works. This study, therefore, focuses its efforts on (1) developing a traffic rating method for bottleneck identification and (2) preparing demonstrative improvement plans for selected road sections among identified bottlenecks.

(2) Traffic Bottleneck

A traffic bottleneck in this study is defined as a road location where there are some deficiencies by which the traffic flow is deteriorated into the condition of congestion.

The most basic issue in developing a traffic rating method is to determine an indicator(s) by which traffic conditions could be evaluated both numerically and objectively. The traffic conditions can be measured and indicated in various forms of traffic features like travel speed, congestion degree and queue length of waiting vehicles due to traffic jam.

(3) Indicator of Traffic Condition

1) Travel speed

An average travel speed over a given road stretch is calculated by "travel distance/travel time" where the travel time includes both running time and waiting time due to traffic congestion and/or traffic signals. The rating method employing travel speed is simple and agreeable to road users' perceptive assessments on traffic conditions. A rating method by travel speed is to compare travel speeds on two adjacent road stretches. If their gap is notably large, it leads to the inference that the section (or point) between the two adjacent stretches is a traffic bottleneck. The rating method by travel speed is suitable to detect a deficient point of road, i.e. mainly intersection.

Other indicators such as congestion degree defined by quotient of traffic volume over traffic capacity on a given road section, queue length of waiting vehicles on a roadway are less reliable than travel speed to assess traffic conditions. Therefore, these indicators are used as an auxiliary means in this study. Queue length means the distance between the frontmost vehicle of the packed-up waiting vehicles on a roadway and the rearmost one stemmed from such obstacles as traffic signals and structural deficiencies.

2) Representative traffic condition

It should, however, be noted that the traffic condition at a given road section changes by hour of the day and by day of the month. In this study, a rating system was developed for the traffic conditions at peak hours. As for daily changes of traffic conditions, an average of several measurements of a certain traffic features was employed to obtain a representative traffic condition at a given road section. In case of travel speed, six (6) measurements are at least necessary.

(4) Traffic Rating Method

From the traffic survey in this study and engineers' observations, it is obvious that intersections constitute a large portion of traffic bottlenecks in the Bangkok road network. As mentioned in preceeding paragraphs, a rating method by travel speed is more suitable to identify spot traffic bottlenecks (mainly intersections). The following, therefore, addresses to development of a road traffic rating method with travel speed being a traffic conditions' indicator.

The concept of the traffic rating method by travel speed is illustrated schematically below. When the speed gap between the travel speed (Vi) on a roadway before an intersection and the travel speed (V_{i+1}) after the intersection is bigger than a critical value the intersection is inferred to be a traffic bottleneck. The critical value of speed gap shall be determined taking into account various factors such as the general traffic conditions in Bangkok, expected service levels of roads and available fund for road improvement etc.

To determine a critical value by statistical method, the speed gap could be expressed either in (1) the absolute value of difference of two travel speeds ($\Delta Vi = V_{i+1} - Vi$) or (2) the ratio of the difference (ΔVi) to the lower travel speed ($K = \Delta Vi/Vi$).

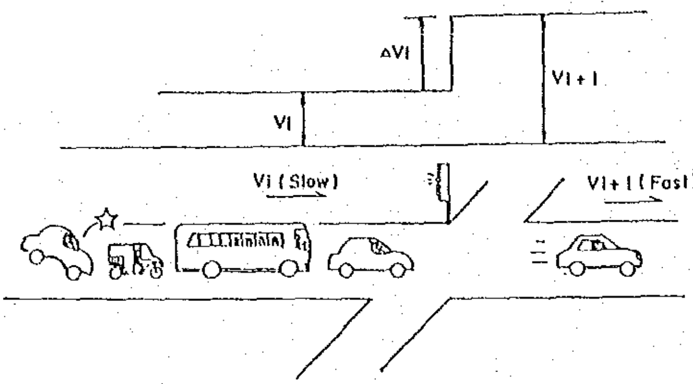


Figure 4.1 Schematic Illustration of Increase of Travel Speed at Bottleneck

The result of the travel speed survey at major intersections carried out in the study area is shown in Figure 4.2.

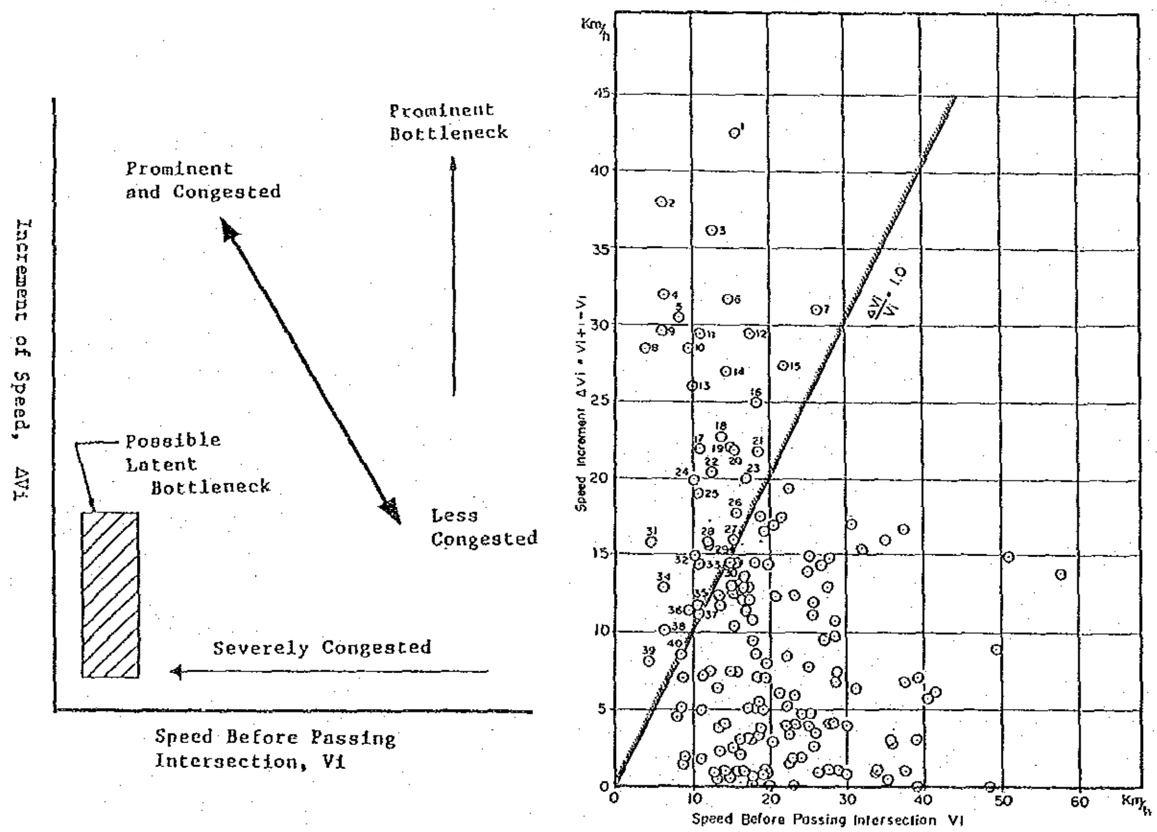


Figure 4.2 Speed Increment and Speed Before Passing Intersection

Those intersections plotted in the lower left-hand corner are severely congested intersections because travel speed is low. Little increase of speed is considered to indicate the existence of bottleneck in the down-stream. These intersections have possibility of being "latent" bottlenecks. Once the bottleneck which is located in the down-stream is eliminated by improvement, these intersections may become new bottlenecks depending on the capacity and traffic volume.

Thus, intersections plotted in the upper left-hand corner are prominent bottlenecks with severe congestion because travel speed is low before passing the intersections and increases drastically after passing them, and vice versa for the intersections ploted in the lower right-hand corner.

Based on thorough considerations and extensive discussions, the ratio (K) in speed gap was adopted as the indicator and the critical value in identifying traffic bottlenecks was set at one ($\Delta Vi/Vi=1.0$). In other words, the intersection, where the travel speed after the intersection is more than double of the travel speed before the intersection, shall be assumed a traffic bottleneck.

(5) Selection for Improvement Planning Locations

28 bottlenecks were identified by the Traffic Rating Method developed in this study. Out of 28 bottlenecks, 11 intersection were selected for demonstration of the road improvement planning.

The selected 11 intersections are shown in Table 4.1 and Figure 4.3.

Table 4.1 Selected 11 Intersections

Intersection	Node Number	Recommended Improvement
1. Rama IV/Si Phraya - Sathon Rds.	023	Flyover
2. Ratchadamnoen Klang/ Ratchadamnoen Nai Rds.	202	Underpass
3. Dindaeng/Ratchaprarop Rds.	613	Flyover
4. Pradiphat/Phahon Yothin Rds.	511	Flyover
5. Petburi/Rama VI Rds.	212	Flyover
6. Pracharat II/Pracha Chuen Rds.	360	At-Grade
7. Sukhumvit/Rama IV Rds.	131	Flyover
8. Petburi/Ramkhamhaeng Rds.	245	At-Grade
9. Rama IV/Kasemrat Rds.	035	At-Grade
10. Dindaeng - Asok Rds.	900	-
11. Petburi Rd./Soi Asok	220	At-Grade

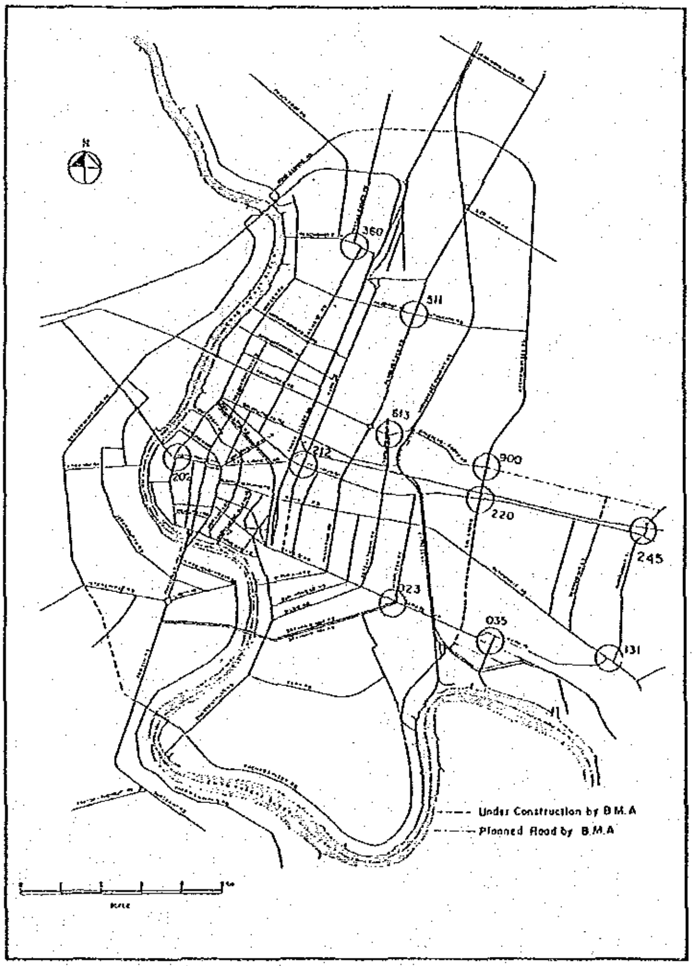


Figure 4.3 Location of Eleven Intersections

(6) Basis of Improvement Planning

1) Engineering aspects

Improvement planning was carried out according to the following policy.

a) Consideration of the importance of the location/route relative to the road network.
b) Balancing the improvement plans along the route.
c) Fixing the target of the improvement.

The process of improvement planning clarifies the major points to be studied during the analysis of existing conditions and the improvement planning. For intersection improvement, three categories of measures were studied.

a) Improvement of signal timing
b) At-Grade improvement
c) Grade-separation improvement

The planning process applied in this study was described as follows:

a) Analysis of existing conditions on traffic flow, constraint, saturation degree, queue length, stopped delay and signal phasing.
b) Planning of improvement alternatives
c) Tabulation of alternatives
d) Calculation of improvement effects
e) Selection by cost and technical aspects (1st step)
f) Benefit/Cost analysis (2nd step)
g) Evaluation

For screening and selection of the improvement alternatives to be a proposed improvement plan, two steps were taken; the first to analyse all the alternatives from the scale of initial investment cost and engineering factors, and choose one or two of them to be brought to the second step, then, the second to analyse the screened alternative(s) by economic factors to be the proposed plan.

For analysis of engineering factors, the improvement effects were calculated for the critical approach and the total intersection on the following items.

a) Saturation degree of the intersection
b) Queue length
c) Stopped delay

2) Economic analysis

For economic analysis of the road improvement plans worked out in this study, comparative assessment of economic benefit and cost was practised. In this analysis, the benefit was assumed as the monetary values of saving in travel time created from decrease in delay time at intersection, and of saving in vehicle operating cost attributable to increase in travel speed on the approaches to the intersection, after implementation of the improvement plan. Also the cost comprised the construction and maintenance/operation costs.

The period of evaluation was set for 10 years judging from the nature of improvement plan being a small scale and a sort of temporary arrangement. As a supplement, 20 year evaluation was also attempted for comparative purpose. The evaluation was made independently for each improvement intersection with an assumption that the existing traffic volume remained unchanged during evaluation period, because the volume was not considered to show remarkable increase due to fixed capacities of adjacent intersections. This might imply that the benefit is estimated to be low.

a) Cost estimation

The cost estimation for each road improvement plan was carried out with the conditions that the total cost comprised the costs for initial construction of road improvement and for maintenance/operation during evalution period, including overhead, profit and tax, land acquisition and compensation costs, contingencies and engineering fees.
The prices of each cost item were based on those in 1986.

b) Estimation of benefit element

The benefit elements applied in this study were assumed as the decrease of total daily vehicle-delay time at an intersection, and saving of total daily vehicle operating cost attributable to increase of travel speed after improvement. These benefit elements were estimated at each improvement location independently and converted to monetary values.

There were two methods applied for the estimation of daily vehicle-delay times; one for oversaturated condition at the improvement location and the other for undersaturated condition by application of estimation method proposed by H.C.M., 1985.
Estimation of travel speed after improvement was carried out taking into account the co-relation between the reduction in travel time and the

increase in travel speed on the approach section to the intersection.

- Unit value of time saving:

  Based on above, estimation of the unit value of time saving in monetary terms per vehicle-hour at 1986 price level was attempted referring to the study on SSES of ETA, 1986 on unit time cost by vehicle type and adopting the results of the motor vehicle O-D survey and the traffic volume count survey of this study on vehicular composition which was assumed to be same at each improvement location. The weighted average value of time saving was calculated to be 22.1 Baht per veh-bour.

- Unit value of vehicle operating cost:

  Vehicle operating cost is composed of several cost elements like costs for fuel and oil consumption, depreciation, etc., and varies according to vehicle type and will change corresponding to travel speed of the vehicle. Estimation of the unit value of vehicle operating cost per vehicle-km at 1986 price level was attempted in the same way as mentioned above referring to the same data.

c) Benefit, cost calculation

Based on identification of cost and benefit elements, benefit/cost analysis was carried out to verify the economic internal rate of return, net benefit and benefit/cost ratio for nine improvement plans. The conditions and assumptions adopted for this analysis were 1) evaluation period being 10 years with a supplement of 20 years, 2) 1986 market price, 3) unit value of time saving being 22.1 Baht per vehicle-hour 4) unit value of vehicle operating cost changing correspondent to travel speed, 5) effective days per year being 260 days, and 6) rate of discount at 5 percent per annum.

The findings of this analysis are presented in the next section being incorporated in the Evaluation of Improvement Effects for each improvement plan.

(7) Planning of Improvement Alternatives

Proposed improvement plan

In accordance with the basis of intersection improvement planning discussed in the preceeding section, preparation of improvement alternatives at eleven (11) selected intersections were studied. Improvement alternatives at ten intersections were carried out. The summary of the proposed improvement plans is presented in Table 4.2.

The typical measures applied for improvement planning are intended for elimination of traffic bottleneck at peak hours, mainly by provision of flyover or underpass and by widening of the existing road or construction of a new road at the selected intersection.

It is to be mentioned that determination for implementation of the proposed improvement plans shall be based on the comprehensive judgement comprising administrative policy on road network taking into account the present and future traffic demands, environmental aspects, availability of fund in addition to engineering and economic evaluation.

Evaluation of Improvement Effects

Effectiveness of proposed improvement plans was analysed mainly by such evaluation factors as the engineering effects of decreases in saturation degree, queue length and stopped delay, and the economic factors in terms of economic internal rate of return, net benefit and benefit cost ratio. Improvement plans were made for ten locations but engineering and economic analysis were carried out for nine locations after close discussion with BMA's counterparts.

It is to be mentioned that this evaluation does not include such factors as the improvement policy and strategy of concerned authority and availability of funds needed for implementation of the plans, which will be dealt with by the road administrators.

The summary of evaluation by engineering factors is presented in Table 4.3, and that by economic factors in Table 4.4, and the combined evaluation of each improvement plan is summarized as follows:

Table 4.2 Summary of Improvement Plan

Location	Recommended Improvement	Direction	Length
1. Rama IV/ Si Phraya-Sathon	Sathon : Two-way, 4-lane flyover Si Phraya-Silom : Two-way, 4-lane (partly 2-lane) continuous flyover	Rama IV direction	Sathon:unknown Si Phraya-Silom: 1,470 m
2. Ratchadamnoen Klang/Nai	One-way, 3-lane underpass	Ratchadamnoen - Phrapinklao	520 m
3. Dindaeng/ Ratchaprarop	At Ratchaprarop : One-way, 2-lane flyover (including 1 reversible) At Expressway : One-way, 2-lane underpass	Dindaeng-Ratchawithi, Dindaeng Rd. direction	420 m 390 m
4. Pradiphat/ Phahon Yothin	Two-way, 3-lane (including 1 reversible) flyover	Pahon Yothin Rd.	520 m
5. Petburi/ Rama VI	One-way, 2-lane flyover	Petburi Rd.	520 m
6. Pracharat II/ Pracha Chuen	At-Grade (new road)	Along Khlong Prapa	730 m
7. Sukhumvit/ Rama IV	Two-way, 2-lane flyover	Rama IV Rd.	770 m
8. Petburi/ Ramkhamheang	At-Grade (Road widening)	All directions	-
9. Rama IV/ Kasemrat	At-Grade (new road)	Beside Soi Ari	250 m
10. Dindaeng-Asok	(Plan coordination with Middle Ring road required)		
11. Petburi/Soi Asok	At-Grade (increase of lane numbers)	Two direction	-

Table 4.3 Summary of Evaluation by Engineering Factors

Name of Intersection	Saturation degree	Max. Queue length (m)	Max. Stopped delay (sec./veh)	Main Traffic flow (PCU/Hour)	Remarks
1. Rama IV/Si Phraya-Sathon Rd.	1.09 0.78	300 50	240 40	2,700	Evening Silom Inter-section, Flyover
2. Ratchadamnoen Klang/ Ratchadamnoen Nai Rd.	0.99 0.80	450 30	670 30	3,400	Morning Underpass
3. Dindaeng/ Ratchaprarop Rd.	0.88 0.51	500 70	240 30	4,000	Morning Flyover
4. Pradiphat/ Phahon Yothin Rd.	0.75 0.69	550 60	350 30	2,500	Morning Flyover
5. Petburi/Rama VI Rd.	1.00 0.74	550 20	260 10	3,500	Morning Flyover
6. Pracharat II/ Prachachuen Rd.	1.06 0.68	120 30	150 30	1,700	Morning At-Grade
7. Sukhumvit/Rama IV Rd.	0.91 0.37	650 40	340 20	3,800	Morning Flyover
8. Petburi/Ramkham-haeng Rd.	1.20 0.81	800 30	760 30	4,100	Morning At-Grade
9. Rama IV/Kasemrat Rd.	1.04 0.82	550 50	420 40	3,900	Morning At-Grade

Note : Upper figure = Before improvement
Lower figure = After improvement

Table 4.4 Summary of Economic Evaluation of Proposed Plans for Road Improvement

(Unit: Cost & Benefit; Baht in million)

Plan No.	Imp. Alt. No.	Improvement Location (Intersection)	Const. Period (Year)	Initial Cost	O/M Cost (per year)	Evaluation Period: 10 Years							Evaluation Period: 20 Years						
						Cost (C)	Benefit (B)			Evaluation			Cost (C)	Benefit (B)			Evaluation		
							Time Saving	VOC Saving	Total Benefit	Net Benefit (B-C)	B/C	IRR		Time Saving	VOC Saving	Total Benefit	Net Benefit (B-C)	B/C	IRR
P-1	3	Rama IV / Si Phraya - Sathon	2	361.7	3.9	377.09	912.86	81.24	994.10	617.01	2.64	0.233	396.51	1651.03	146.94	1797.97	1401.46	4.53	0.268
P-2	3	Rachadamnoen Klang / Nai	3	134.4	4.2	150.14	133.83	12.58	146.41	-3.74	0.98	0.031	171.05	260.75	24.51	285.26	114.21	1.67	0.107
P-3	2	Din Daeng / Rachaprarop	3	98.5	3.7	113.30	212.52	39.74	252.26	138.96	2.23	0.189	131.72	414.07	77.43	491.50	359.78	3.73	0.234
P-4	3	Pradipat / Phahon Yothin	2	76.7	1.1	81.64	168.40	64.50	232.90	151.25	2.85	0.255	87.12	304.57	116.65	421.22	334.10	4.83	0.287
P-5	2	Petburi / Rama VI	2	45.6	1.2	51.90	179.47	61.38	240.85	188.94	4.64	0.397	57.87	324.59	111.01	435.60	377.73	7.53	0.415
P-6	1	Pracharat II / Pracha Chuen	1	24.1	0.5	27.65	26.86	10.50	37.36	9.71	1.35	0.107	30.14	45.67	17.85	63.52	33.38	2.11	0.160
P-7	3	Sukhumvit / Rama IV	2	70.4	1.5	77.96	156.17	20.30	176.47	98.51	2.26	0.207	85.42	282.45	36.71	319.16	233.74	3.74	0.245
P-8	1	Petburi / Ramkhambeng	1	30.5	1.0	37.61	288.87	121.04	409.91	372.30	10.90	0.951	42.59	491.16	205.80	696.96	654.37	16.37	0.952
P-9	1	Rama IV / Kasemrat	1	36.5	0.6	40.76	73.27	32.10	105.37	64.60	2.58	0.272	43.75	124.59	54.57	179.16	135.41	4.09	0.299

Source: JICA Team Estimation

Remarks:
1. Costs and Benefits are calculated at 1986 price.
2. Rate of discount: 5% per annum.
3. Traffic flow and volums are set at 1986 level.
4. Weighted average time value: 22.1 Baht per vehicle-hour.
5. VOC stands for vehicle operating cost, comprising the costs of fuel, oil, tyres, depreciation, maintenance for parts and labour, interest and age depreciation.

i) Rama IV/Si Phraya - Sathon Intersection

The proposed improvement plan at these intersections to provide a continuous flyover gives the largest effects of all in terms of both engineering and economic aspects. This plan will allow the main traffic flow of 2,700 PCU/hr. at the Silom intersection in peak hours to be transferred to the flyover. As Mass Transit System is planned here, the close coordination with ETA is required.

In terms of engineering effects, saturation degree, queue length and stopped delay on the main traffic flow in peak hours can be reduced from 1.09 to 0.78, from 300 m to 50 m, and 240 seconds to about 40 seconds, respectively at the Rama IV/Silom intersection. In terms of economic effects, this plan can yield the net benefit of nearly 600 million Baht with the B/C ratio of 2.6 and the IRR of 0.23 in 10 years.

It is concluded that this plan can be designated to be excellent.

ii) Ratchadamnoen Klang/Ratchadamnoen Nai Intersection

The proposed plan is to improve this intersection by providing an underpass along Ratchadamnoen Klang Road to the approach of the Phrapinklao Bridge, in order to preserve the existing historical and environmental conditions around Sanam Luang. By this plan the main traffic of about 3,400 PCU/hr. in peak hours at this intersection will be transferred to the underpass.

This plan will improve the saturation degree, queue length and stopped delay from 0.99 to 0.80, 450 m to 30 m and 670 sec. to 30 sec. respectively on the main flow in peak hours. It also yields the net benefit of 110 million Bath with the B/C ratio of 1.6 and the IRR of 0.107 in 20 years although in 10 years the B/C ratio is nearly break-even.

This plan can be regarded as the plan of necessity bearing moderate improvement effects with the environmental conditions being given the first priority.

iii) Dindaeng/Ratchaprarop Intersection

The plan is to provide a combination of a flyover at this intersection and an underpass crossing under the Expressway in east-west direction on the same road.

By this improvement, saturation degree, queue length and stopped delay will be reduced from 0.88 to 0.51, 550 m to 70 m, and 240 sec. to 30 sec., respectively on the main flow in peak hours by transferring the main traffic flow of about 4,000 PCU/hr. to the flyover and connecting underpass. The net benefit yielded by this plan accounts for about 130 million Bath with the B/C ratio of 2.2 and the IRR of 0.19 in 10 years.

This plan is regarded as a highly effective one.

iv) Pradipat/Phahon Yothin Intersection

A three-lane with one resersible lane flyover is proposed in the north-south direction at this intersection. It is located in the north commercial area of Bangkok. This plan will let the main traffic flow of about 2,500 PCU/hr. in peak hours to be transferred to this flyover, by which saturation degree, queue length and stopped delay will be reduced from 0.75 to 0.69, 550 m to 60 m and 350 sec. to 30 sec. respectively. The net benefit for 10 year period accounts for about 150 million Baht with the B/C ratio of 2.8 and the IRR of 0.26.

This plan is considered to be fairly effective.

v) Petburi/Rama VI Intersection

The improvement plan is to extend the existing flyover to the eastward by 530 m. crossing over this intersection. By this plan saturation degree, queue length and stopped delay will be reduced from 1.00 to 0.74, 550 m to 20 m, and 260 sec. to 10 sec. on the main flow in peak hours whose traffic volume counted at 3,500 PCU/hr.

The economic net benefit yielded in 10 years accounts for 180 million Baht with the B/C ratio of 4.6 and the IRR of 0.40. It is to be mentioned that this plan requires close coordinations with ETA's Second Stage Expressway plan.

This plan is regarded as highly effective both in engineering and economic factors.

vi) Pracharat II/Pracha Chuen Intersection

This plan is to construct a new road along Khlong Prapa by land acquisition of about 2,800 sq.m. By implementation of this plan, saturation degree, queue length and stopped delay of the main traffic flow of about 1,700 PCU/hr. in peak hours will be improved from 1.06 to 0.68, 120 m. to

30 m., and 150 sec. to 30 sec. Due to the need for land acquisition which raises the project cost, the net benefit and the B/C ratio are relatively small. In 10 years, they will be 9 million Baht and 1.3 respectively, and the IRR is 0.107.

This plan can be said effective in engineering factors.

vii) <u>Sukhumvit/Rama IV Intersection</u>

This plan is to provide a flyover on Sukhumvit Road, by which the main traffic flow with about 3,800 PUC/hr. in peak hours will be transferred to the flyover, and saturation degree, queue length and stopped delay will be reduced from 0.91 to 0.37, 650 m. to 40 m. and 340 sec. to 20 sec. respectively.

The net benefit yielded by this plan will be 98 million Baht with the B/C ratio of 2.2 and the IRR of 0.21 in 10 years.

This plan can be said fairly effective both in engineering and economic factors.

viii) <u>Petburi/Ramkhamhaeng Intersection</u>

This plan is to widen the road widths of four-leg roads as one of at-grade improvement plans requiring only a small land acquisition. Implementation of this plan will improve the main traffic of 4,100 PUC/hr. in peak hours by reduction of saturation degree, queue length and stopped delay from 1.20 to 0.81, 800 m to 30 m., and 760 sec. to 30 sec. respectively. The net benefit yielded in 10 years accounts for about 370 million Baht with the B/C ratio of 10.9 and the IRR of 0.95.

This plan is considered to be fairly effective both in engineering and economic factors.

ix) <u>Rama IV/Kasemrat Intersection</u>

This plan is to improve the alignment of offset intersection by providing a new road branching from Soi Ari, by which saturation degree, queue length and stopped delay of the main traffic flow of 3,900 PCU/hr. in peak hours will be improved from 1.04 to 0.82, 550 m to 50 m, and 420 sec. to 40 sec. respectively. The net benefit in 10 years accounts for 64 million Baht with the B/C ratio of 2.5 and the IRR of 0.27.

This plan is considered to be fairly effective in engineering and economic factors.

x) Petburi / Soi Asok Intersection

This plan is to increase the number of lanes by channelization, by which smooth traffic flow will be secured.

It is concluded that all the ten improvement plans worked out and evaluated in this study prove to be effective from comprehensive viewpoints of evaluation, although there are some varieties in the extent of their effectiveness.

5. PAVEMENT REHABILITATION

(1) Scope of Study

As the riding quality on roadways is directly governed by pavement conditions, the importance of pavement maintenance works equal that of road improvement works. Road pavements will rapidly deteriorate when timely maintenance work are neglected. This necessitates to find out in time the pavement sections which are in need of remedial works. This study, therefore, proposes pavement rating system to identify distressed pavement sections. Pavement rehabilitation plan for selected sections were also prepared with intention to demonstrate planning practices.

(2) General Practice in Pavement Evaluation

Pavement rating methods were proposed mainly by modifying the rating methods currently employed in Japan where pavement conditions and axle loads of vehicles are similar to these in Bangkok. To evaluate pavement conditions quantitatively, there are two methods in practice in Japan;

- Present Serviceability Index (P.S.I.), and
- Maintenance Control Index (M.C.I.).

The P.S.I. method had been originally developed in the U.S.A. based on the correlation between the result of mechanical surveys on pavement conditions and the result of visual assessment at the same road sections by road engineers from the viewpoint of present serviceability. This method was modified in Japan. This P.S.I. method is at present applicable to only asphalt pavement.

The M.C.I. method was developed in Japan, taking into account not only serviceability but also necessity and extent of rehabilitation. The formula in the method was worked out based on the correlation between the result of mechanical surveys on pavement conditions and the result of road engineers' assessments for the road in the study area.

(3) Pavement Survey

To modify the above mentioned rating methods, following types of pavement surveys were carried out at selected one hundred eleven (111) road sections in the study area (66 at asphalt pavement and 45 at cement concrete pavement). The survey sites were selected in such a manner that they could represent the general pavement conditions of the road network in the study area.

- Crack survey
- Longitudinal roughness survey
- Rutting survey
- Visual evaluation of pavement condition

(4) Pavement Rating Method

The development of pavement rating methods in the study is to modify the current methods in Japan so as to best suit the road and traffic conditions in Bangkok. The results of modification, applying the data obtained from the pavement surveys, are as follows.

a) Asphalt Pavement

M.C.I. = $10.0 - 0.88C^{0.3} - 2.03\sigma^{0.2} - 0.22D^{0.7}$ (R=0.83)
(When the value of rutting depth is small)
M.C.I. = $10.0 - 0.97C^{0.3} - 2.61\sigma^{0.2}$ (R= 0.81)
P.S.I. = $3.64 - 0.22\sqrt{C} - 0.9 \log \sigma$ (R= 0.79)

where C : crack ratio (%)
σ : standard deviation of longitudinal roughness (mm)
D : average depth of rutting (mm)
R : multiple correlation coefficient

b) Cement Concrete Pavement

M.C.I. = $10.0 - 0.83C^{0.3} - 2.65\sigma^{0.2}$ (R=0.59)

In this study, the P.S.I. formula for asphalt pavement was discarded in the light of the fact that the multiple correlation coefficient (R) of P.S.I. is smaller than that of M.C.I., and the main aim of the study is to identify pavement sections in need of rehabilitation works (P.S.I. is based on only riding quality).

(5) Extent of Pavement Rehabilitation

The extent of pavement rehabilitation could be generally decided from Table below.

Table 5.1 Evaluation of Pavement Condition by M.C.I. Value

MCI Value	Required Extent of Rehabilitation
MCI $\geqq 5.0$	Unnecessary to repair
$4.0 \leqq$ MCI < 5.0	Maintenance
$3.0 \leqq$ MCI < 4.0	Partial repair
MCI < 3.0	Full scale repair

(6) Pavement Evaluation of Damage Type Criteria

The general evaluation of pavement conditions shall be carried out by application of M.C.I. method, but M.C.I. method tends to neglect independent type damages. Therefore, in order to supplement the general evaluation, it is necessary to conduct the evaluation by damage type criteria as shown in Table 5.2 and 5.3.

Table 5.2 Damage Type Criteria for Rehabilitation (Asphalt Pavement)

Road Classification \ Item	Rutting Depth (mm)	Bump (mm)		Skid Resistance Coefficient	Longitudinal Roughness (mm)	Cracking Ratio (%)	Pot Hole Diameter (cm)
		Abutment	Culvert Box				
Highways with Heavy Traffic	30 - 40	60	60	0.25	4.0 - 5.0(σ) (3 m profile)	30 - 40	20
Other Highways	40	60	-	-	-	40 - 50	20

Table 5.3 Damage Type Criteria for Rehabilitation (Cement Concrete Pavement)

Road Classification \ Item	Rutting Depth (mm)	Bump (mm)	Skid Resistance Coefficient	Longitudinal Roughness (mm)	Cracking Index(cm/m^2) (Develop the bottom of the slab)	Joint Damage
Highways with Heavy Traffic	30 - 40	15	0.25	5.0 (σ) (3 m profile)	30	If the damage can be found
Other Highways	40 - 50	-	-	-	50	

(7) Pavement Rehabilitation Plan

According to the M.C.I. method proposed in the preceding paragraphs, the M.C.I. values at 27 sections out of the 111 surveyed pavement sections fall below 5 points. The details of the sections are as follows;

Table 5.4 Evaluation of Pavement Condition at 111 Road Sections

M.C.I. value / Pavement Type	4≦M.C.I.<5 (Maintenance)	3≦M.C.I.<4 (Repair)	M.C.I.<3 (Full Repair)	Sub Total	M.C.I≧5 (Uncessary to repair)	Total
Asphalt Pavement	15	7	None	22	44	66
Cement Concrete Pavement	5	None	None	5	40	45
Total	20	7	0	27	84	111

Five sections for rehabilitation planning were selected from the above 27 sections. The selected five sections are located on the roads listed in the Table 5.5. Proposed types of rehabilitation are also presented in the table.

The pavement design for selected five sections were carried out according to the methods described in "TECHNICAL GUIDELINE FOR PAVEMENT REHABILITATION".

Table 5.5 Road and Type of Rehabilitation

Road Name	Type of Rehabilitation
Itsaraphab Road (As)	Overlay
Charoen Krung Road (As)	Overlay
Sutthisan Road (As)	Overlay
Petburi Road (Co)	Joint sealer
Nang Linchi Road (Co)	Patching, Partial reconstruction

Note : As : Asphalt pavement

Co : Cement Concrete pavement

6. TRAFFIC SAFETY

(1) Scope of Study

Road traffic accidents in Bangkok have rapidly increased in the past few years as the number of vehicles increased. Traffic accidents could be reduced when a comprehensive measure including improvement of road environments by engineering practices, road users' education and law enforcement has been implemented in complete harmony. In this study, traffic safety is discussed mainly from engineering approaches on the assumption that enforcement of laws and education of drivers are to be coordinated by the respective agencies concerned.

The main activities in the study are;

- to collect relevant information and data regarding to traffic accidents,
- to develop identification methods of hazardous road sections,
- to prepare traffic safety plans for selected locations, and
- to evaluate economic viability of safety plans.

(2) Accident Investigation and Recording

As for investigation and recording of traffic accidents on roads in Bangkok, the Police Department of the Ministry of Interior, through its 65 police stations is responsible. The police stations investigate and record traffic accidents, then simplified accident records in a specified format are supposed to be forwarded to the headquarters. However, since police stations are not forced to forward specified format to the headquaters, the accident data available at the police headquarters are not sufficient enough to analyze accidents in detail.
Although there is no common recording format among the police stations, most of police stations' records contain the following information on a traffic accident;

- year, month, date, day and time
- name of district,
- location of accident,
- number of fatality and injury,
- type of accident,
- type of vehicle involved, and
- cause of accident.

However, collision diagrams which are very helpful for accident analyses and preparation of road improvement plans are not available from the original records of the police stations, except the brief explanation of accident situation by words.

(3) Data Collection

The study team visited the police stations and copied necessary data from the police's original records. The data collection by the team was made in two ways. One is for the study roads for which all the data available were collected, inclusive of information obtained through interviews with traffic police officers. The other is for the minor roads in the study area and the roads outside the study area. The data obtained for these roads are limited to the extent so that only general analyses for the whole traffic accidents in Bangkok can be made.

The size of traffic accident data (equals to number of traffic accidents) collected from the police stations is as follows;

Table 6.1 Size of Collected Traffic Accident Data

Area	Road Length	Year		
		1983	1984	1985
BMA Area	1,883 Km			
No. of Accident		12,564	13,093	6,578
No. of Fatality		627	639	361
No. of Injury		4,888	5,061	2,306
Study Road	350 Km			
No. of Accident		4,321	4,271	1,948
No. of Fatality		152	158	93
No. of Injury		1,702	1,827	768

Note : Traffic Accident Data in 1985 are from January through June.

Source : Study Team

(4) Data Compilation for Analysis

All the collected accident data were stored in a microcomputer in three types of files, i.e., Basic Accident Data File, Accident Master File and Road Section File.

The Basic Accident Data File is an original file in this study and it is developed into two other files. In this file, accident locations are fully coordinated with control links or primary nodes in the road inventory system.

The Accident Master File was prepared for the year 1983, 1984 and 1985. In this file, selected information from accident data, traffic volume data and road information were assorted by each traffic accident. Therefore, the information in this file can be retrieved on the basis of each accident.

The Road Section File was prepared separately for mid-block sections and intersections. In this file, the same information in the Accident Master File were assorted by road section so that all information can be retrieved on the basis of each road section.

(5) Traffic Accident Analysis

1) Traffic accident in Thailand and Bangkok

The number of accident, fatality and injury in Bangkok in the year 1985 are about 77%, 24% and 52% of the total numbers of Thailand, respectively, whereas the vehicles registered in Bangkok account for about 35% of the total of Thailand. Although the share of fatality in Bangkok is relatively small at present, it is noteworthy that the number of fatality has been on up-trend continuously for the past 9 years with an average growth rate of 9%.

Table 6.2 Traffic Accident in Thailand and Bangkok

Description		1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Number of Accident	Thailand	13,831	16,583	18,669	23,120	17,742	16,361	16,047	17,864	18,445	18,420
	Bangkok	7,965	10,482	11,680	12,045	11,190	11,802	9,794	13,674	14,092	14,295
	Bangkok per Thailand	0.58	0.63	0.63	0.52	0.63	0.72	0.61	0.77	0.76	0.77
Fatality	Thailand	3,764	2,545	3,952	8,365	4,493	2,760	3,091	3,005	2,908	2,700
	Bangkok	403	474	534	571	624	631	689	708	736	657
	Bangkok per Thailand	0.11	0.19	0.14	0.07	0.14	0.23	0.22	0.24	0.25	0.24
Injury	Thailand	10,183	9,306	10,568	21,639	13,392	9,297	9,340	9,026	5,949	8,289
	Bangkok	3,628	4,751	4,844	5,032	4,585	4,810	3,693	4,551	4,672	4,330
	Bangkok per Thailand	0.36	0.51	0.45	0.23	0.34	0.51	0.40	0.50	0.79	0.52

Source : Research and Planning Division, Police Department
Central Traffic Police Division, Police Department

2) Type of accident

On the study road, vehicle-vehicle type (including motorcycle) is the largest (76%) in number of accident, followed by vehicle-pedestrian type (20%) and accident plunging into fixed object.

3) Collision pattern

Rear-end collision is the largest (25%), followed by right-turn collision (20%) and side contact (17%). The vehicle-pedestrian pattern accounts for 11%.

4) Cause of accident

Improper driving speed is the highest (47%), followed by improper overtaking (27%) and improper turning (24%).

(6) Method for Identification of Hazardous Road Sections

1) Identification Method

A "hazardous road section" is defined as the site where a high risk of traffic accident exists and remedial measures are required. To propose the identification methods applicable to BMA roads, thorough and extensive reviews and discussions on the following methods are made;

- accident number method,
- accident density method,
- accident rate method,
- number-volume method,
- number-rate method,
- rate-volume method, and
- statistical method.

In this study, rate-volume method and number-volume method are selected for mid-block sections and intersections, respectively. The identification criteria in the rate-volume method and number-volume method are determined in the following manner.

2) Identification Criteria

Statistical approach was adopted to determine the criteria and its procedure is as follows;

- to determine road sections which are judged to be hazardous by using the statistical method,
- to plot the results on a rate-volume diagram for mid-block sections and a number-volume diagram for intersections. The circled points in the rate-volume diagram below show the "hazardous mid-block sections" identified by the statistical method, and
- to determine the criterion line for each traffic-volume-rank in such a manner so that it can separate the sections between hazardous and nonhazardous.

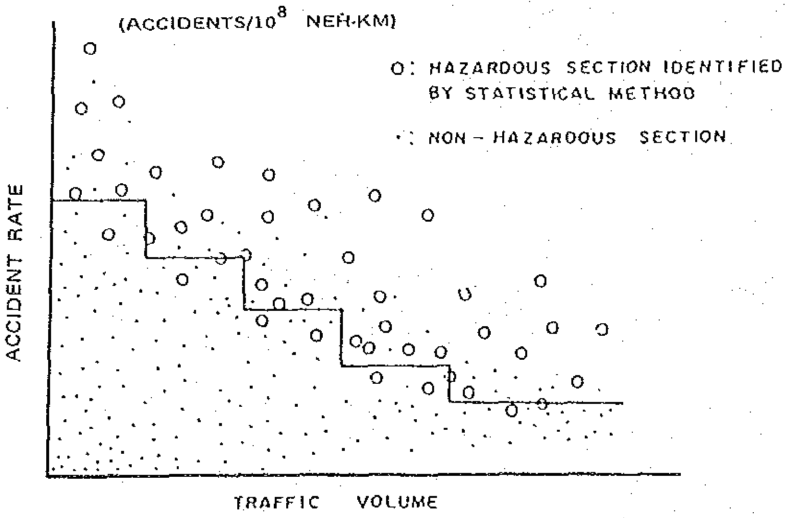


Figure 6.1 Identification Criteria in Rate-Volume Method

The judgement whether "hazardous" or "non-hazardous" can be made by the formula of

$$Zi = \frac{(Yi - yi)}{\sqrt{yi}}$$

where Yi : Actual number of accident at section (i)
yi : Statistically estimated number of accident at section (i)

The road sections of which Zi values exceed 1.96 are judged hazardous with a confidence level of 95%. The above diagram is drawn plotting the values of accident rate ($Ri = Yi/(Xi \times Li \times 365 \times 10^{-8})$), where Xi and Li stand for daily traffic volume and section length at section (i).

The estimation of accident's number (yi) is usually made applying regression models or multiple regression models. In the study, the following equations are obtained.

1) For mid-block section;

$$ri = 53.85 + 572503 / Xi$$

where ri : Estimated accident rate.

Xi : Average daily traffic volume.

2) For intersection;

$$yi = 0.0002\ Xi + 0.47\ Ki - 3.56$$

where yi : Estimated number of accident

Xi : Average daily inflow traffic volume

Ki : Number of lanes.

The determined criteria by the categories of average daily traffic volume are as follows;

Table 6.3 Proposed Identification Criteria for Mid-block Section

Average Daily Traffic Volume (veh/day)	Identification Criteria (Accident Rate)
- 15,000	500
15,001 - 30,000	150
30,001 - 50,000	125
50,001 - 70,000	100
70,001 - 100,000	75
100,001 -	75

Table 6.4 Proposed Identification Criteria for Intersection

Average Daily Inflow Traffic Volume (Veh./day)	Identification Criteria (No. of Accidents)
- 30,000	5
30,001 - 60,000	5
60,001 - 100,000	10
100,001 - 140,000	15
140,001 - 200,000	15
200,001 -	15

3) Results of Identification

The number of hazardous mid-block sections and intersections identified by the proposed criteria is as follows.

Table 6.5 Number of Hazardous Road Sections

	No. of Sections	No. of Accidents at whole section	No. of Hazardous Sections	No. of Accidents at Harzardous Sections
Mid-block Section	659	2,645	61 (9.3%)	1,256 (47.5%)
Intersection	393	1,632	51 (13.0%)	890 (54.5%)

The number of accidents on hazardous mid-block sections which account for 9.3% of total number of mid-block sections, is 47.5% of total accidents on all the mid-block sections.

The number of accidents at hazardous intersections which have 13.0% of share, accounts for 54.5% of total accidents at all the intersections.

(7) Traffic Safety Planning

As the case study of engineering approaches to traffic safety, traffic safety plans for the 10 road locations, which are selected from hazardous road sections identified by the proposed methods, are prepared.

For the preparation of safety plans, additional accident data collection, topographic surveys, additional traffic surveys and site investigation were carried out. Then, major problems at each safety planning location are identified based on results from analyses of accident pattern, collision diagram, site condition and traffic condition. Finally, suitable safety measures to cope with those major problems are prepared. Their locations and proposed major safety measures are presented in Figure 6.2.

In parallel with preparation of safety plans, installation costs and maintenance/operation costs for 10 years period on safety measures are estimated based on unit costs at 1986 year's price.

(8) Economic Evaluation of Safety Plans

The economic evaluation of traffic safety plans at 10 selected hazardous locations are attempted to identify the net benefit (B-C) and benefit/cost ratio (B/C) with the evaluation period of 10 years. The benefits are assumed as the monetary values of the persons saved from fatality and prevented from injury and those of properties prevented from damage by implementation of the safety plan and these benefits are a part the social benefit. On the other hand, the costs comprise the installation and maintenance costs of the safety devices adopted in the safety plan.

The conditions and assumptions adopted in this evaluation are those that the prices of benefits and costs are based on the market prices in 1986, rate of reduction is 5% per annum and the number of traffic accidents is fixed at 1986 level. The unit prices of personal fatality, injury and the property damage are estimated at 0.9, 0.09 and 0.02 million Baht respectively.

The benefit and cost analysis proves that every 10 safety plan yielded considerable net benefit and reasonable benefit/cost ratio respectively, whose summary is shown in Table 6.6.

Regarding the net benefit with the evaluation period of 10 years, five out of ten plans yield more than 10 million Baht, and the smallest net benefit at 0.8 million Baht. With regard to the benefit/cost ratio, 6 plans record the ratios over 4.0.

It is also revealed that by implementation of 10 safety plans, numbers of traffic accidents and their casualties were estimated to reduce by 178 cases and 90 persons every year, respectively, showing an average reduction rate of 42 percent.

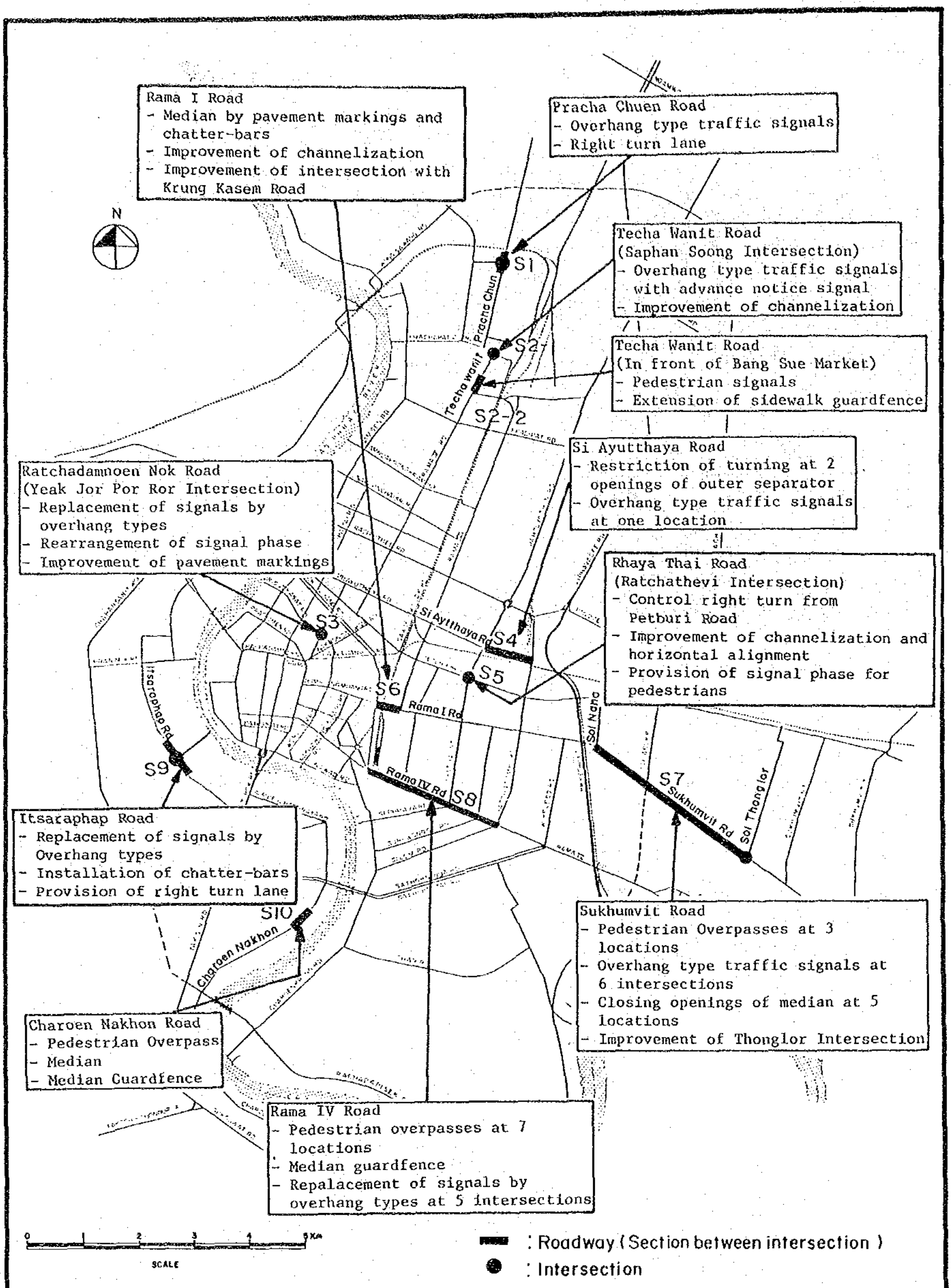


Figure 6.2 Road Locations for Safety Plans and Proposed Major Safety Measures

Table 6.6 Summary of Economic Evaluation for Traffic Safety Plans

(Unit : Cost & Benefit : Baht in million)

Road Segment No.	Evaluation Period : 5 Years				Evaluation Period : 10 Years			
	Cost	Benefit	Net Benefit (B-C)	B/C	Cost	Benefit	Net Benefit (B-C)	B/C
S1	1.357	1.380	0.023	1.02	1.687	2.448	0.761	1.45
S2-1	1.015	1.334	0.319	1.31	1.307	2.367	1.060	1.81
S2-1	0.983	6.944	5.961	7.06	1.201	12.312	11.111	10.25
S3	1.089	3.484	2.395	3.20	1.476	6.180	4.704	4.19
S4	1.123	1.113	△ 0.010	0.99	1.559	1.974	0.415	1.27
S5	0.781	3.099	2.318	3.97	1.112	5.497	4.385	4.94
S6	1.507	3.759	2.252	2.49	1.685	6.668	4.983	3.96
S7	19.652	21.586	1.934	1.10	24.202	38.289	14.087	1.58
S8	20.400	21.373	0.973	1.05	22.300	37.911	15.611	1.70
S9	0.936	7.398	6.462	7.90	1.112	13.125	12.013	11.80
S10	2.488	7.669	5.181	3.08	2.721	13.603	10.882	5.00

Source : JICA Team Estimate

Remarks
1. Nos. of accident and casualties are based on 1986 survey by JICA Team.
2. The costs and benefits are calculated at 1986 price.
3. Unit values of fatality, injury and property damage are;
   1) fatality = ฿ 0.9 million
   2) injury = ฿ 0.09 million
   3) property damage = ฿ 0.02 million
4. Traffic volume is set at 1986 level.
5. Rate of Discount : 5% per annum

7. TECHNICAL GUIDELINE

(1) Scope of Study

Efficient and economical road construction, improvement and maintenance are attained by applying reasonable technical standard. BMA, having accumulated knowledge and information on highway engineering, it is timely and suitable to develop a comprehensive technical standards applicable to all the aspect of road planning and designing.

Through the study of planning for road improvement, pavement rehabilitation and traffic safety measures, technical guidelines are proposed, as follows.

1. Road planning
2. Traffic safety planning
3. Pavement rehabilitation planning

They are prepared with reference and due considerations to the followings:

- relevant standards prevailing in Thailand
- relevant standards prevailing in other countries
- current BMA practices on highway engineering.

(2) Contents

The main contents of the technical guideline are as follows.

1. Road Planning
   - 1.1 Road Planning
     - Classification of Roads
     - Design Speed
     - Cross Section
     - Alignment and Sight Distance
     - At-grade Intersection
     - Grade Separation
   - 1.2 Bridge Design
     - Loads
     - Cross Section
   - 1.3 Traffic Capacity
     - Basic Freeway Segments
     - At-grade Intersection
2. Traffic Safety Devices
   - Guardfence
   - Delineator
   - Sidewalk

- Crossing Facility for Pedestrian
- Street Lighting
- Traffic Signal
- Traffic Signs
- Pavement Markings

3. Pavement Rehabilitation
   - Survey for Evaluation of Pavement Condition
   - Rehabilitation of Asphalt Pavement
   - Rehabilitation of Cement Concrete Pavement
   - Pavement Design for New Construction

(3) Main Items of Technical Guideline

1) Road Planning

a) Classification of roads in BMA

1. The roads of BMA are classified as shown in Table 7.1.

Table 7.1 Classification of BMA Roads

Class	Design Speed (km/h)		Number of lane		Access Control	Remarks
	Urban	Suburban Rural	Urban	Suburban Rural		
1. Major Trunk Road	60 ~ 80	80 ~ 100	≧ 4	≧ 4	* F.P.N	
2. Major Road	40 ~ 60	60 ~ 80	≧ 4	≧ 2	N.	
3. Minor Road	30 ~ 50	40 ~ 60	≧ 2	≧ 2	N.	
4. Access Road	20	30 ~ 50	≧ 1	≧ 1	N.	

F : Full control of access
P : Partial control of access
N : No control of access

*Full access control is included here for the future construction of high standard road and may be used only in very limited cases at present. Hence, other parts of this guideline do not cover designs for fully access-controlled road.

b) Design speed

1. The design speeds should be the values shown in Table 7.2. They should be selected according to the classification of road and the area.

Table 7.2 Design Speed

Class	Type (Area)	
	Urban	Suburban, Rural
1. Major Trunk Roads	60 ~ 80	80 ~ 100
2. Major Roads	40 ~ 60	60 ~ 80
3. Minor Roads	30 ~ 50	40 ~ 60
4. Access Roads	20	30 ~ 50

c) Design vehicle

1. Major Trunk Roads and Major Roads should be designed for semi-trailers and small-sized motor vehicles. Whereas, other roads should be designed for large-sized motor vehicles and small-sized motor vehicles.

2. The dimensions of design vehicles are shown in Table 7.3.

Table 7.3 Design Vehicle

Type of vehicles	Length	Width	Height	Front over-hang	Wheel base	Rear over-hang	Minimum turning radius
Small sized motor vehicle	4.7	1.7	2.0	0.8	2.7	1.2	6
Large sized motor vehicle	12.0	2.5	3.8	1.5	6.5	4.0	12
Semi-trailer	16.5	2.5	3.8	1.3	front 4 rear 9	2.2	12

Source : Japan - the Road Structure Ordinance (enacted in 1970 according to the Road Law)

d) Elements of cross section and their combination

1. Standard widths of cross section elements are shown in Table 7.4. The values of the median, shoulder, sidewalk and cycle track shown in Table 7.4, are minimum widths, and the value for the greenbelt is a standard width.

Table 7.4 Cross Section Elements

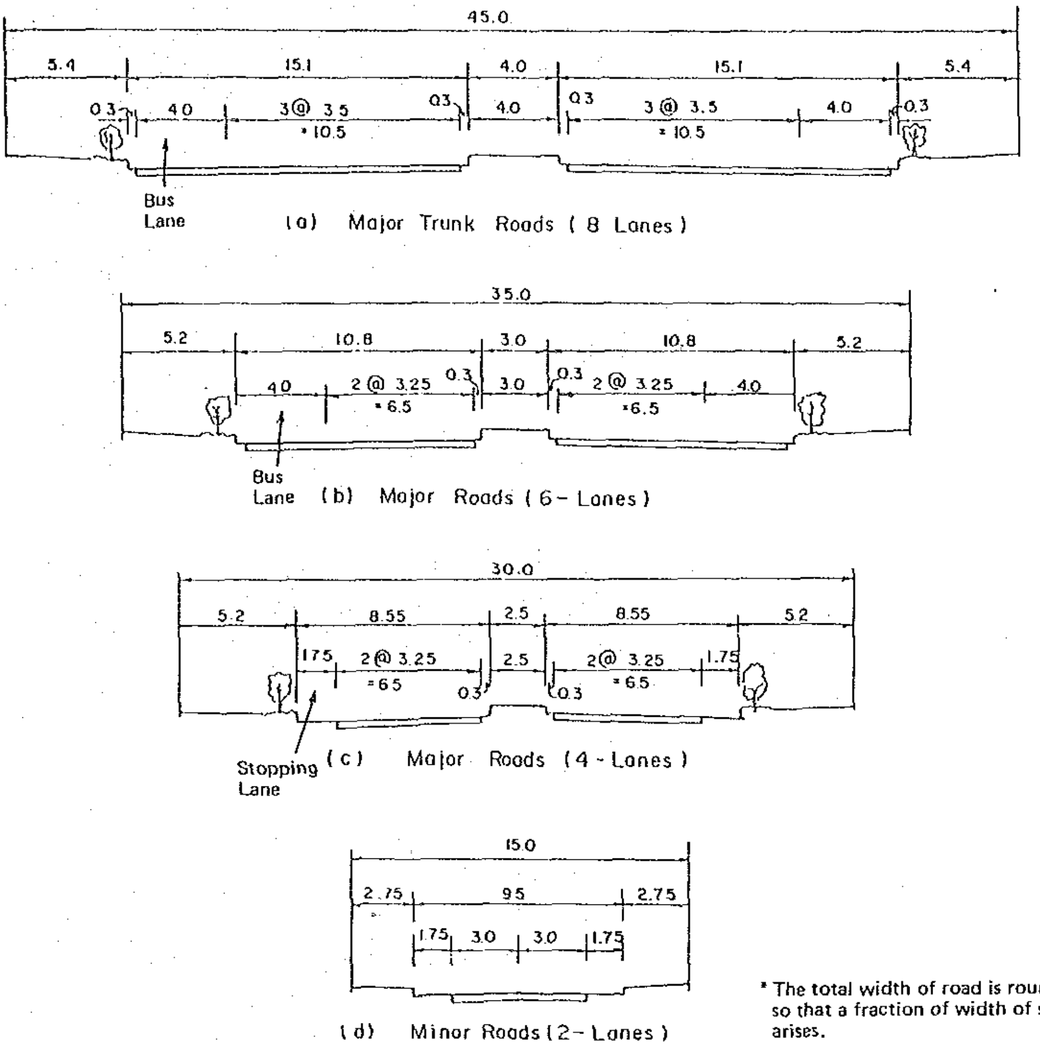
Class	Lane	Median		Shoulder*	Sidewalk	Cycle track	Green belt	Stopping lane
		Median	Marginal strip					
1. Major Trunk Roads	3.5	over 1.5(1.0)	0.30(0.25)	over 0.75	over 5.00(3.50)	over [2.00(1.00)]	over [1.50]	[2.50(2.00)]
2. Major Roads	3.25	1.5(1.0)	0.30(0.25)	0.50	5.00(3.50)	[2.00(1.00)]	[1.50]	[2.50(1.75)]
3. Minor Roads	3.00	[1.5(1.0)]	[0.30(0.25)]	0.50	2.75(2.0)	[2.00(1.00)]	[1.50]	[2.00(1.75)]
4. Access Roads	4.00 or 3.00 roadway			0.50	1.50(1.0)	[2.00(1.00)]	[1.50]	[2.00(1.50)]

Note : [ ] : Only when necessary
( ) : Applied in the case of bridge, etc.
* : Desirable value is 2.0 m

e) Standard cross section

1. When widths and the combination of elements of road cross section are designed, they should be determined in consideration of the standard width. However, in unavoidable cases, such as where the conditions of the area and the traffic are unfavorable, they may not be done based on standard width.

Examples of actual combinations of cross section elements are shown in Figure 7.1.



* The total width of road is rounded, so that a fraction of width of sidewalk arises.

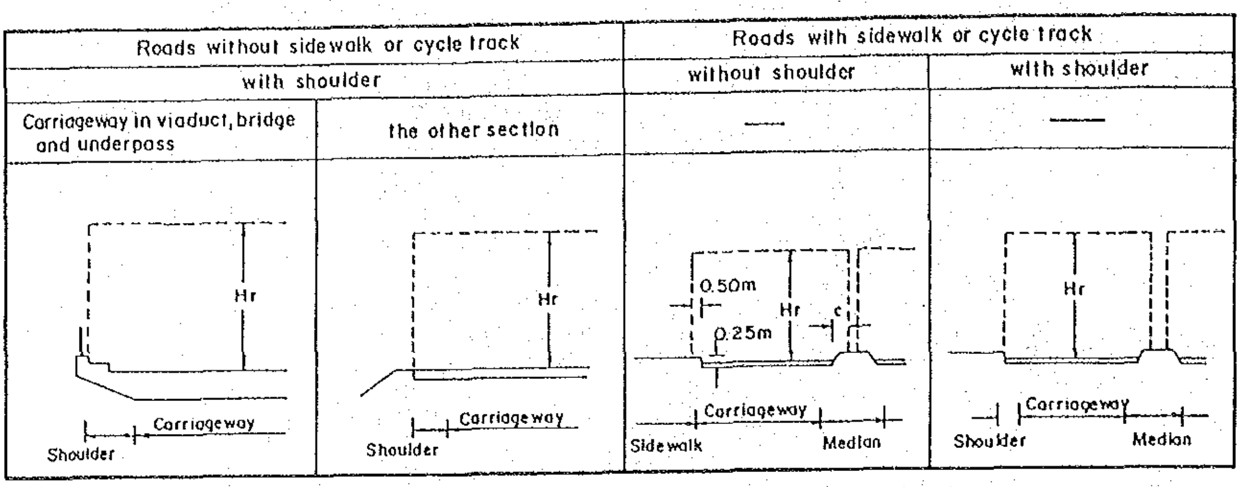
Figure 7.1 Standard Cross Section

f) Clearance

1. Clearances on roads are shown in Figure 7.2 for the carriageway and Figure 7.3 for sidewalk.

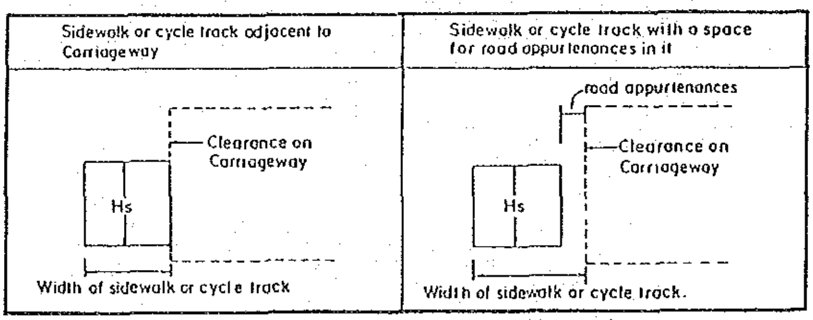
2. Vertical clearance on carriageway is 5.0 m. In an unavoidable case, such as for a topographical reason, the value may be reduced to 4.5 m.

3. Vertical clearance on sidewalk is 2.5m. However, in unavoidable cases, the value may be reduced to 2.4 m.



Hr : 5.0m. In case it is necessary because of the topographical condition or for any other reasons, the value can be reduced to 4.5 m.

Figure 7.2 Clearance on Carriageway



Hs : 2.5 In unavoidable case the value can be reduced to 2.4 m

Figure 7.3 Clearance on Sidewalk

g) <u>Elements of alignment</u>

1. Alignment of road is an important factor to ensure safety, smoothness and comfort of traffic, and it directly influences the driving speed of vehicles. Therefore, values of design elements are all provided according to the design speed. They are shown in Table 7.5.

Table 7.5 Elements of Alignment

Design speed (km/h)	Radius of curve (m) Maximum superelevation rate 6%	10%	Length of transition curve (m)	Maximum Grade (%)	Minimum stopping sight distance (m)	Radius of vertical curve (m) Crest	Sag
100	460	380	85	3	160	6,500	3,000
80	280	230	70	4	110	3,000	2,000
60	150	120	50	5	75	1,400	1,000
50	100	80	40	6	55	800	700
40	60	50	35	7	40	450	450
30	30		25	8	30	250	250
20	15		20	9	20	100	100

h) At-grade intersection

1. An intersection shall be designed so as not to have more than five intersecting legs, except when it is located in a special place like in front of a station.

2. At an intersection where two or more roads join or intersect at grade, if necessary, a turning lane, speed change lane or traffic island is to be provided, and the corners of intersection shall be cut to ensure unobstructed sight.

3. When turning lane and/or speed change lane are provided at an intersection, the width of a lane other than a turning or speed change lane may be reduced to 3.0m on Major Trunk Roads and Major Roads in urban areas. On other roads except, the width may be reduced to 2.75 m.

4. The standard width of a turning lane and speed change lane is 3.0 m.

5. When a turning lane and/or speed change lane are provided at an intersection, transition runoff should be provided as appropriate, according to the design speed.

i) Grade separation

1. When two roads having four and more lanes each excluding climbing lane, turning lane, and speed change lane are intersecting mutually, the intersection should be separated in grades as a general rule. However, when the grade separation is unsuitable due to traffic conditions, or in an unavoidable case, such as due to a

topographical reason, this rule may be waived.

2. When a intersection is separated in grades, if necessary, a road connecting with the intersecting through traffic lanes mutually shall be provided.

2) Bridge Design

a) Live load

i) Live load on the carriageways of bridges

1. Live loadings on the carriageways of bridges or incidental structures shall consist of standard trucks or lane loads that are equivalent to truck trains. Two systems of loadings are provided, the H loading and the HS loadings - the HS loadings heavier than the corresponding H loadings.

2. Four classes of loading should be used according to the classification of the road; H20, H15, HS20 and HS15 (AASHTO Standard).

   On the carriageway of bridges of three-classification Roads except Access Roads, H20 shall be placed.

   On Access Roads, H15 shall be placed.

   On the bridges of specific routes expected to carry heavy traffic volumes of large-sized motor vehicles and semi-trailers, in Major Trunk Roads and/or Major Roads, HS loading must be used.

ii) Live load on the sidewalk of bridges

1. Sidewalk floors, stringers and their immediate supports shall be designed for a live load of 415 Kg/m^2 of sidewalk area.

2. Girders, trusses, arches and other members shall be designed for the following sidewalk live loads:

   Spans 0 to 7.5m in length .....415 Kg/m^2
   Spans 7.5 to 30.0m in length .....300 Kg/m^2
   Spans over 30.0m in length .....according to the following equation

$$P = (1575 + \frac{48000}{L}) \; (\frac{16.8 - W}{164})$$

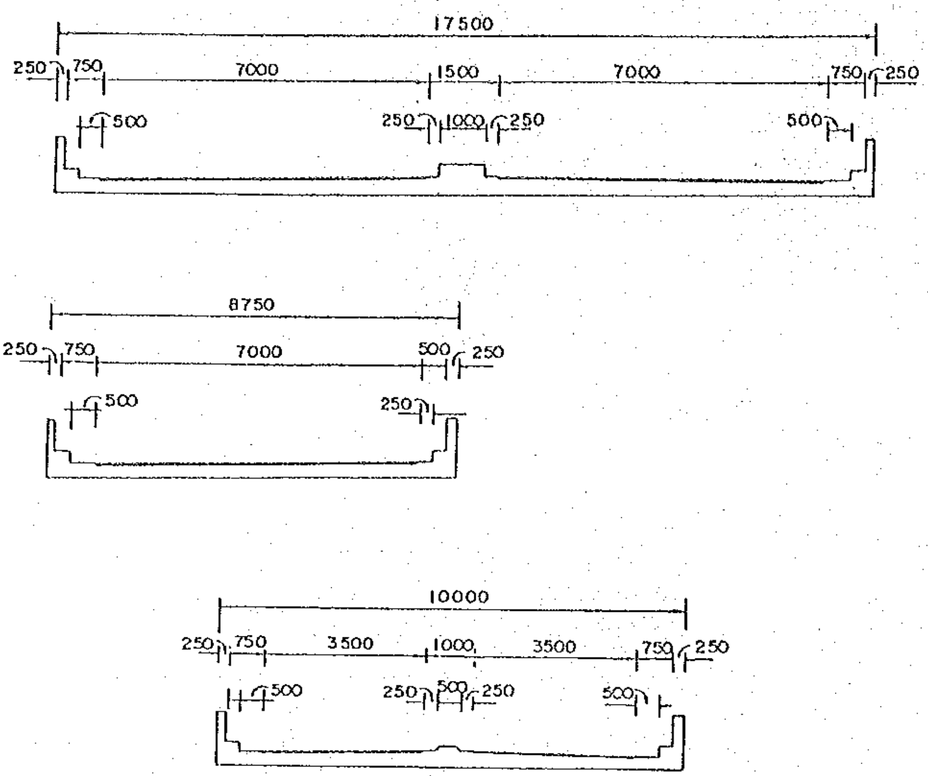
in which; P = live load per square meters, max. 300 kg/m^2;
L = load length of sidewalk in meters;
W = width of sidewalk in meters.

b) Bridge cross section

1. In an urban area, the standard widths of road elements of bridge cross sections should be the same values as those at ordinary road section. However, in unfavorable places, the widths may be reduced to the values in parentheses shown in Table 7.4.

2. In suburban and rural areas, the widths of each element may be reduced to the values in parentheses shown in Table 7.4. However, it is desirable that the widths shall be the same values as those at ordinary road section, if possible.

3. When the widths and combination of cross section elements of flyover and underpass are designed, they should be determined in consideration of standard widths shown in Table 7.4. The standard cross sections of flyovers on Major Trunk Roads and Major Roads are shown in Figure 7.4 and 7.5.

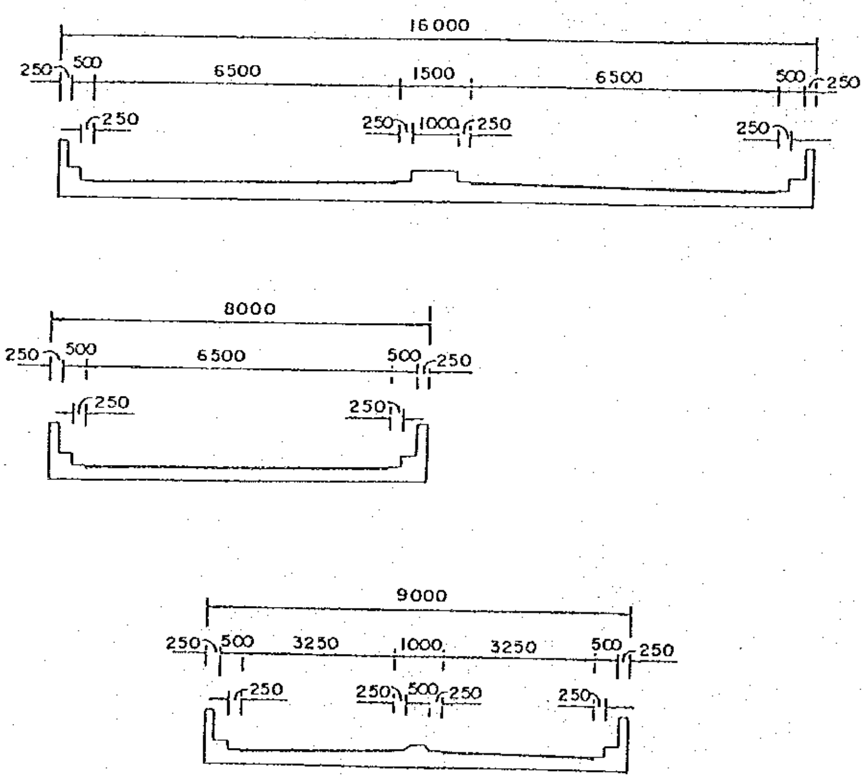


2-Way 4-Lane

1-Way 2-Lane

2-Way 2-Lane

Figure 7.4 Standard Cross Section (Flyover) (Major Trunk Roads) Design Speed = 80 km/h



2-Way 4-Lane

1-Way 2-Lane

2-Way 2-Lane

Figure 7.5 Standard Cross Section (Flyover) (Major Roads) Design Speed = 60 km/h

3) Traffic Capacity

a) Basic freeway segments

i) Level of service

1. Level of service criteria for basic freeway segments area given in Table 7.6 for design speed element. Level of service is indicated by the ratio of the average travel speed to the design speed. The volume-to-capacity ratios and maximum service flow rates indicated in the table are expected to exist under ideal conditions.

Table 7.6 Levels of Service of Basic Freeway Segments

Level of Service	$V_D \geq 80$ Km/h			$V_D \leq 60$ Km/h		
	V_A/V_D	v/c	MSF (PCPHL)	V_A/V_D	v/c	MSF (PCPHPL)
I	≥ 0.80	0.75	1,650	≥ 0.85	0.65	1,450
II	≥ 0.70	0.85	1,850	≥ 0.75	0.85	1,850
III	≥ 0.55	1.0	2,200	≥ 0.60	1.0	2,200
IV	< 0.55	*	*	< 0.60	*	*

V_A = Average travel speed (Km/h)

V_D = Design speed (Km/h)

MSF = Maximum service flow rate per lane under ideal conditions for multilane road

v/c = Maximum volume - to - capacity ratio associated with LOS

* = Highly variable, unstable

NOTE : All values of MSF rounded to the nearest 50 pcph

ii) Service flow rate

1. Service flow rate for LOS_i is obtained from the following equation;

$$SF_i = MSF_i \times N \times f_L \times f_c \times f_R$$

where:

SF_i = service flow rate for LOS_i under prevailing roadway and traffic conditions for N lanes in one direction, in vph.

$MSF_i = c_j \times (v/c)_i$

MSF_i = maximum service flow rate per lane for LOS_i (Level of Service) under ideal conditions, in pcphpl;

$(v/c)_i$ = maximum volume-to-capacity ratio associated with LOS_i;

c_j = capacity under ideal conditions for freeway element of number of lanes j; 2200 (pcphpl) for multilane road, 2500 (pcph/two-way) for two-lane two-way road, the value of c_j is synonymous with service flow rate for LOS III in Table 7.6.

N = number of lanes in one direction of the freeway

f_L = factor to adjust for the effect of restricted lane width

f_c = factor for lateral clearance

f_R = factor for roadside condition

b) At-grade intersection (signalized intersection)

i) Saturation flow rate

1. The saturation flow rate can be obtained by multiplying the ideal saturation flow rate and the adjustment factors for a variety of prevailing conditions that are not ideal, as follows;

$$S = S_o \times N \times f_w \times f_g \times f_{HV} \times f_{RT} \times f_{LT}$$

Where:

S = saturation flow rate under prevailing condition, in vphg.

S_o = ideal saturation flow rate per lane, in pcphgpl;

N = number of lanes,

f_W = adjustment factor for lane width,

f_g = adjustment factor for approach grade,

f_{HV} = adjustment factor for heavy vehicles in the traffic stream,

f_{RT} = adjustment factor for right turns in the shared lane,

f_{LT} = adjustment factor for left turns in the shared lane,

ii) Ideal saturation flow rate

1. The values of "ideal" saturation flow rate are shown in Table 7.7.

Table 7.7 Ideal Saturation Flow Rate, S_o

Type of lane	Ideal saturation flow rate (pcphgpl)
Through	2,200
Left-turn	2,000
Right-turn	2,000

pcphgpl : passenger cars per hour of green time per lane

4) Traffic Safety Devices

a) Guardfence

Summary of Warrants

1. Roadside guardfence

1) Sections having serious roadside hazards
- Sections which have obstacles, such as big trees, traffic signals and houses, in the 2m zone to the carriageway.
- Sections along the water such as pond, river, canal and ditch, which depth is more than 1.5 m.
- Sections on bridges and flyovers.

2) Low-standard design sections
- Curves having radius of 200 m or less.
- Down slopes having 4% or more gradient.
- Sections where the carriageway width or number of lanes is reduced abruptly.

3) Proximities to bridges, culverts, etc.
- Approaches to bridges, viaducts, tunnels or culverts.
- Sections where pier, abutment, retaining wall or other rigid structure are in the 2m zone to the carriageway.

4) Sections which have numbers of accidents
- Sections where considerable number of run-off-road accidents happened or is suspected to happen.

2. Median guardfence (width of less than 10 m)
- Sections where 85 percentile speed is 80 km/hr or more and meet one of the following conditions:
  * longitudinal gradient is 3% or more, or
  * curve radius is 750 m or less.
- Sections where median guardfence installation is necessitated because of high running speed.
- Sections where carriageway crossing by pedestrians should be prohibited.
- Sections where prevention of glare by headlights (high-beam) of vehicles from the opposite direction is desirable.

3. Sidewalk guardfence

1) Guardfence to restrain the errant vehicle
- Sections where vehicles are suspected to run into pedestrians on sidewalks due to poor horizontal alignment.
- Sections where prevailing speed is considerably high and safeguard of pedestrians is considered to be requisite.
- Sections on bridges with sidewalk

2) Guardfence to discourage pedestrians from crossing the carriageway
- Sections where carriageway crossing by pedestrians should be prohibited.

3) Guardfence to prevent pedestrians from dropping off
- Sections along the roadside hazard such as ditch, river or low-height ground.

b) Delineator

Summary of Warrants

1. Post delineator

Post delineators may be installed along the following sections except where guardfences are installed:
- Curve sections of which radius is 300 m or less, and approaches to the curve.
- Sections where number of lanes or width of carriageway changes abruptly.
- Sections where there are many accident records of run-off type at nighttime or where found as necessary by engineering study to ensure safe traffic flow.

2. Raised pavement marker (Chatter-bar)

Series of raised pavement markers may be installed along:
- Curve sections of which curve radius is 150 m or less.
- Sections where center line crossing by vehicles is to be prohibited.
- Boundary of chevron marking which is drawn on the pavement near to rigid hazards, e.g., raised traffic island, pier in the carriageway, etc.

c) Sidewalk

Summary of Warrants

In sub-urban areas, sidewalks may be constructed at sections where traffic volume on outer lanes of both directions per day is 3,000 or more and pedestrian volume is 250 or more. For the roads in urban areas, it is desirable, regardless of the above traffic volume, to construct sidewalks on any road, when found necessary to do so and no land acquisition problems exist.

d) Crossing facility for pedestrians

Summary of Warrants

1. Crosswalk
   - More than 100 pedestrians cross carriageway per hour.
   - A number of school children cross carriageway.
   - Designated as walking spaces within intersections.
   - Vehicle traffic makes it difficult for a number of pedestrians to cross carriageway.

2. Pedestrian Refuge Island

Pedestrian refuge islands may be installed at the sections where pedestrians can not cross carriageway in one movement of crossing and forced to wait for traffic gaps in the middle part of carriageway with 4 or more lanes.

Pedestrian refuge islands should, in principle, be installed in combination with crosswalks.

3. Pedestrian Overpass/Underpass

Pedestrian overpasses/underpasses, at mid-block sections or at non-signalized intersections, are warranted under the following conditions.

i) The number of crossing pedestrians per hour exceeds 100 persons at a peak hour, and the condition of traffic volume and width of carriageway meet the range indicated by the oblique line in Figure 7.6. (For the crossing of school children, Figure 7.7 should be used.)

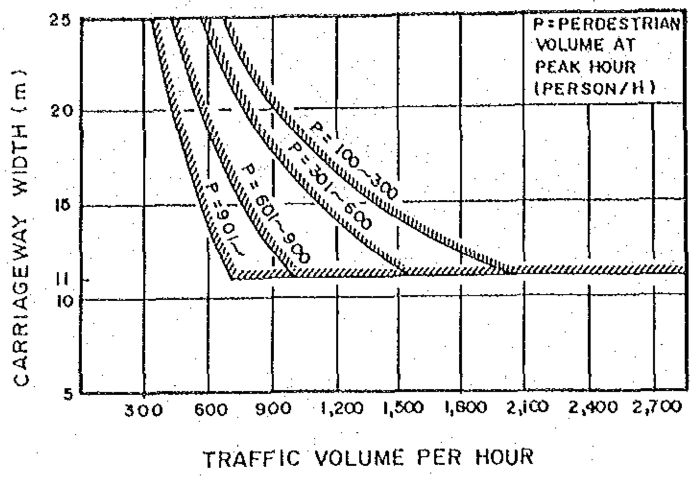


Figure 7.6 Warrant of Pedestrian Overpass/Underpass

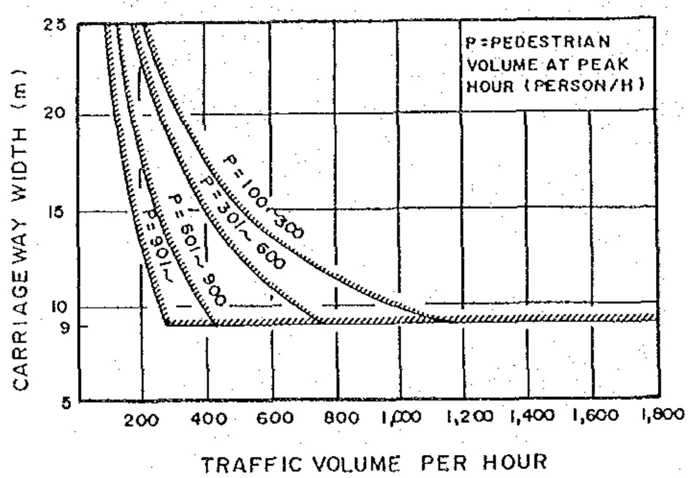


Figure 7.7 Warrant of Pedestrian Overpass/Underpass for School Children

ii) The following conditions are met:

- The width of carriageway exceeds 25 meters, and there are no proper space to construct median or refuge island where pedestrians can wait for traffic gap.
- Pedestrian volume is so heavy that vehicle traffic is affected to a large extent.
- No pedestrians are allowed to cross to ensure high running speed of vehicles on roads such as expressway; or
- When pedestrian volume is heavy at such as locations, within 200 meters from railway crossing, immediate vicinity of grade separated road, or sub-standard sight distance, where pedestrian safety cannot be kept by at-grade crossing.

e) Street lighting

Summary of Warrants

1. Continuous Lighting

Continuous lighting in urban areas are warranted where:
- ADT is 25,000 vehicles or more.
- Adjacent areas have high illumination levels, which interferes with driver's visibility.
- Pedestrian volume at night is considerably heavy.
- Road sections shorter than 1 km which are located between two lighted sections.

Continuous lighting in rural area may not be warranted.

2. Specific Lighting

Specific lightings are warranted at:
- Intersections where traffic signals are warranted and installed.
- Crosswalks where pedestrian signals are warranted and installed.
- Sections where cross section abruptly changes.
- Sharp bend or steep gradient section.
- Toll plaza and its approaches.
- Sections where number of accidents at nighttime is much more compared with daytime.
- Sections where studies indicate that street lightings may be expected to significantly reduce the night accident rates.

Summary of Design Factor for Street Lighting

1. Average Road Surface Luminance

Table 7.8 Recommended Average Road Surface Luminance

Unit: cd/m^2

Roadside Condition / Road Class	A	B	C
Major Trunk Roads	1.0 (0.7)	0.7 (0.5)	0.5 (-)
Major Roads Minor Roads	0.7 (0.5)	0.5 (-)	0.5 (-)

Note: Values in parentheses are applied to roads where median is furnished with glare screen.

2. Light Distribution Type

Table 7.9 Selection of Light Distribution Type

Road Class \ Roadside Condition	A	B	C
Major Trunk Road	semi-cut-off	cut-off	cut-off
Major Road Minor Road	semi-cut-off	semi-cut-off	cut-off

f) Traffic signal

Summary of Warrants

1. Pretimed Signal

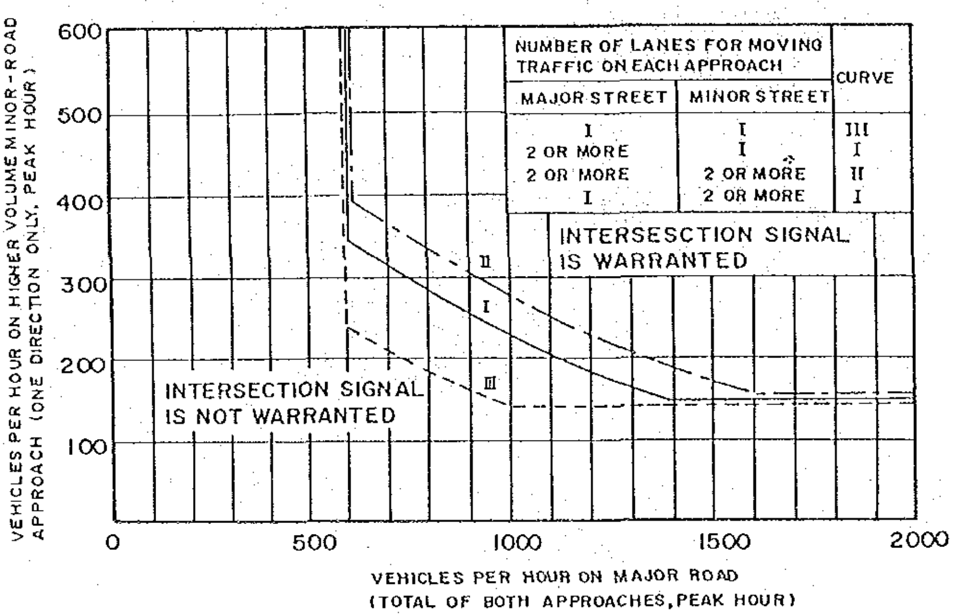


Figure 7.8 Warrant for Traffic Control by Pretimed Signals

2. Semi-Traffic-Actuated Signal

Table 7.10 Warrant for Traffic Control by Semi-Traffic-Actuated Signals

	Vehicle per hour on major road (total of both approaches)	Vehicle per hour on higher-volume minor road approach (one direction only)
Peak hour traffic volume	900 or more	100 or more

3. Pedestrian Signal

Table 7.11 Warrant for Traffic Control by Pedestrian Signals

	Vehicle per hour on the street (total of both directions)	Pedestrian per hour on the crosswalk crossing the road
Peak hour traffic volume	650 or more	200 or more

4. Accident Prevention

Table 7.12 Warrant for Traffic Accident Prevention by Traffic Signals

	Accidents Preventable by Traffic Signals
Number of Accidents within a 12-month Period	5 or more

g) Traffic signs

A review was made on the "Standard for production and installation of reflective traffic signs" that are currently in use by the Traffic Engineering Division (TED) of BMA.

h) Pavement markings

A review was made on the "Standard for pavement markings by reflective thermoplastic" that are currently in use by the Traffic Engineering Division (TED) of BMA.

5) Pavement Rehabilitation

a) Survey for evaluation of pavement condition

1. Survey items
   i) Visual assessment
   ii) Detailed pavement survey
      - Cracking
      - Longitudinal roughness
      - Rutting depth
      - Bump
      - Deflection

b) Rehabilitation of asphalt pavement

1. Evaluation of pavement condition

   i) Evaluation by M.C.I. method

$$M.C.I. = 10-0.88C^{0.3}-2.03\sigma^{0.2}-0.22D^{0.7}$$

where:

C : crack ratio (%)

σ : standard deviation of longitudinal roughness(mm)

D : average depth of running (mm)

Evaluation of pavement condition by M.C.I. values (See Table 7.13)

Table 7.13 Evaluation of Pavement Condition by M.C.I. Value

MCI Value	Required Extent of Rehabilitation
MCI ≧ 5.0	Unnecessary to repair
4.0 ≦ MCI < 5.0	Maintenance
3.0 ≦ MCI < 4.0	Partial repair
MCI < 3.0	Full scale repair

ii) Evaluation by damage type criteria

Table 7.14 Damage Type Criteria for Rehabilitation (Asphalt Pavement)

Item / Road Classification	Rutting Depth(mm)	Bump (mm) Abutment	Bump (mm) Culvert Box	Skid Resistance Coefficient	Longitudinal Roughness (mm)	Cracking Ratio (%)	Pot hole diameter (cm)
Highways with heavy traffic	30 - 40	60	60	0.25	4.0-5.0(σ) (3m profile)	30 - 40	20
Other highways	40	60	-	-	-	40 - 50	20

2. Rehabilitation method

i) Typical maintenance methods
- Patching
- Surface treatment
- Partial reconstruction
- Cutting
- Grooving

ii) Typical repair methods
- Overlay
- Cutting and Reconstruction
- Reconstruction

c) Rehabilitation of cement concrete pavement

1. Evaluation of pavement condition

i) Evaluation by M.C.I. method

$$M.C.I. = 10 - 0.83C^{0.3} - 2.65\sigma^{0.2}$$

where:

C : cracking index (cm/m)

σ : standard deviation of longitudinal roughness(mm)

Evaluation of pavement condition by M.C.I. values (see Table 7.13)

ii) Evaluation by damage type criteria

Table 7.15 Damage Type Criteria for Rehabilitation (Cement Concrete Pavement)

Item / Road Classification	Rutting Depth (mm)	Bump (mm)	Skid Resistance Coefficient	Longitudinal Roughness (mm)	Cracking Index(cm/m^2) (Develop the bottom of the slab)	Joint Damage
Highways with Heavy Traffic	30 - 40	15	0.25	5.0 (σ) (3 m profile)	30	If the damage can be found
Other Highways	40 - 50	-	-	-	50	

2. Rehabilitation method

i) Typical maintenance methods
- Injection of joint sealer into the joint and cracking sites
- Patching
- Surface treatment
- Partial reconstruction
- Injection

ii) Typical repair methods
- Overlay
- Reconstruction

d) Pavement design for new construction

1. Pavement design classification by traffic volume

Table 7.16 Pavement Design Classification by Traffic Volume

Pavement design Classification	One Way Daily Traffic of Heavy Vehicles
L	Less than 100
A	100 to 250
B	250 to 1,000
C	1,000 to 3,000
D	More than 3,000

2. Asphalt pavement design

Target value T_A and for the total pavement thickness H (See. Table 7.17)

Table 7.17 T_A Target Values and for the Total Pavement Thickness, H, cm

Design C.B.R. equal to or larger than	TA ,H by Pavement Design Classification (cm)									
	L		A		B		C		D	
	T	H	TA	H	TA	H	TA	H	TA	H
2	17	52	21	61	29	74	39	90	51	105
3	15	41	19	48	26	58	35	70	45	83
4	14	35	18	41	24	49	32	59	41	70
6	12	27	16	32	21	38	28	47	37	55
8	11	23	14	27	19	32	26	39	34	46
12	–	–	13	21	17	26	23	31	30	36
20 or more	–	–	–	–	–	–	20	23	26	27

where TA: thickness of hot bituminous mixture for surface course converted from the total pavement thickness

H : total pavement thickness

3. Cement concrete pavement design

i) Relationship between design C B R and base course thickness

Table 7.18 Relationship between Design C B R and Base Course Thickness

(Unit:cm)

Pavement Design Classification \ Design CBR of Sub-grade	2	3	4	6	8	12 and over
L and A	50	35	25	20	15	15
B, C, and D	60	45	35	25	20	15

ii) Standard thickness of concrete slab

Table 7.19 Standard Thickness of Concrete Slab

Pavement design Classification	Thickness of Concrete Slab (cm)
L	15 (20)
A	20 (25)
B	25
C	28
D	30

Note : Figures in parentheses are under bending strength of 40 kg/cm^2 in L and A traffic.

8. REVIEW ON ROAD ORGANIZATION OF BMA

The objective of this review is to provide the BMA with useful information and comments for structuring an organization by which the BMA can efficiently function its road administration under the rapidly changing environments.

A review has been made on the BMA's road organization from the standpoints of i) compliance with the rapidly changing social, economic and technological environments, ii) improvement of administrative performance, and iii) upgrading of personal capability in road planning, design, implementation, maintenance and traffic management. The review has been paid special attention so that the outcomes of this study can be continuously utilized by the BMA personnel in charge after completion of the study.

The review comprised identification of the existing organizational structures, staffings and work procedures of relevant BMA departments and divisions concerned with road and traffic managements, such as DPW,CPD,TED and District Offices. It was made by means of interviews and discussions with the BMA counterparts and other officials in charge, including those in some of the agencies of the central government such as MOI, MOC and so on.

The outcome of the review consists of a brief observation on each organizational unit and its duty concerning road and traffic management, and a general view on the functional improvement and restructural consideration of road related organization of the BMA.

The brief observation deals with three (3) aspects. The first is on a new duty and function which the BMA might assume on traffic management in Bangkok Metropolis, on which an appropriate organizational structure with sufficient manpower is suggested to be set up. The second is on the continuous utilization of the JICA study outputs suggesting encouragement of active practice of proposed systems, methods and guidelines, and their proper maintenance, effective updating and modifications. The third is on the organizational units in which several divisions are suggested to enlarge their functions or to be divided to define clear-cut responsibility and so on.

The general view suggest four (4) points in functional improvement, namely, strengthening of planning capability, effective coordination among each organizational unit for plan-do-check function, encouragement of effective training for upgrading of the personnel capability and active introduction of computer.

It also suggested a need for detailed study on the possibility of restructuring the existing road organization by type of public work facility for improvement of administrative efficiency.

9. OTHER STUDIES

(1) Flood Prevention for Road

The roads in Bangkok suffer from floods frequently during the rainy season almost every year. In the year 1983, for instance, more than two hundred (200) road sections within the study area were inundated and the traffic in the whole area was seriously paralyzed. Although flood issues should be, in principle, tackled by authorities other than road authority, the road authority also has to pay due attentions to road inundation measures.

The road inundation records in the year 1983 and 1986 were collected and marked precisely on the road network. They are expected to be a great help to the road administrators in planning road improvement and maintenance works.

This study also briefly looks into the causes of floods in Bangkok and gives an overview of the existing drainage facilities and future flood control plans in connection with road inundation problems. Based on the available information materials, some suggestions for flood prevention plans for major roads on the part of roads were given.

(2) Common Duct

Roadways in urban areas provide space to accommodate a number of public utilities which are essential to social and economic activities. Traffic disturbance accrued from repetitious digging is, however, a nuisance to the public. A solution to this problem is to construct common ducts which will eliminate repetition of road excavation once they are completed. A brief description based on the Japanese experiences with common ducts was presented as general information.

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