land use. Investigation of the land use constraints can be performed by using existing land use maps and topographic maps. Example relations of transport land use and other types of urban land use may be summarized in Table 4-5.

Table 4-5 Urban Land Use and Their Relation to Transport Systems
- An Example of Land Use Constraints

Land Use	Relation to Transport Systems
- Historic Area - Military Reserve	- Restriction in road improvement and construction
- Residential Area - Educational	- Heavy traffic and through traffic are restricted. Preserve environmental amenity.

When the grid data on the existing land use and topographic conditions as well as socio-economic indices, are available 'Potential Surface Analysis (PSA)' or 'Sieve Analysis'[1] may be applied to the analysis of land use constraints and road-network location. Figure 4-11 shows an example output applied to Tha Rua - Tha Lan general planning area. This kind of map is very useful in the design stage of transport planning.

4.3 Formulating Planning Strategy

Goals and Objectives

The concept of goals and objectives in an essential component of public planning. They influence almost all stages of the planning process. The result of the analysis of existing systems, goals and objectives have to be formulated to provide the planning strategies.

Transport goals are the reflection of social values and transport users' interests. (e.g. Table 4-6, 4-7)

The major goal of urban transport planning is to ensure efficient flows of persons and goods in response to the demand but also be based on the strategy for future urban structure development, support of various forms of urban activities and the increase of standards of the urban environment.

Goals are stated in general terms that correspond to the existing transport problems. Objectives, on the other hand, are stated with quantitative targets in mind. Examples of goal and objective statements are expressed as follows:

[1] Land-use analysis methods that are explained in VOL. IV: LAND USE PLANNING MANUAL.

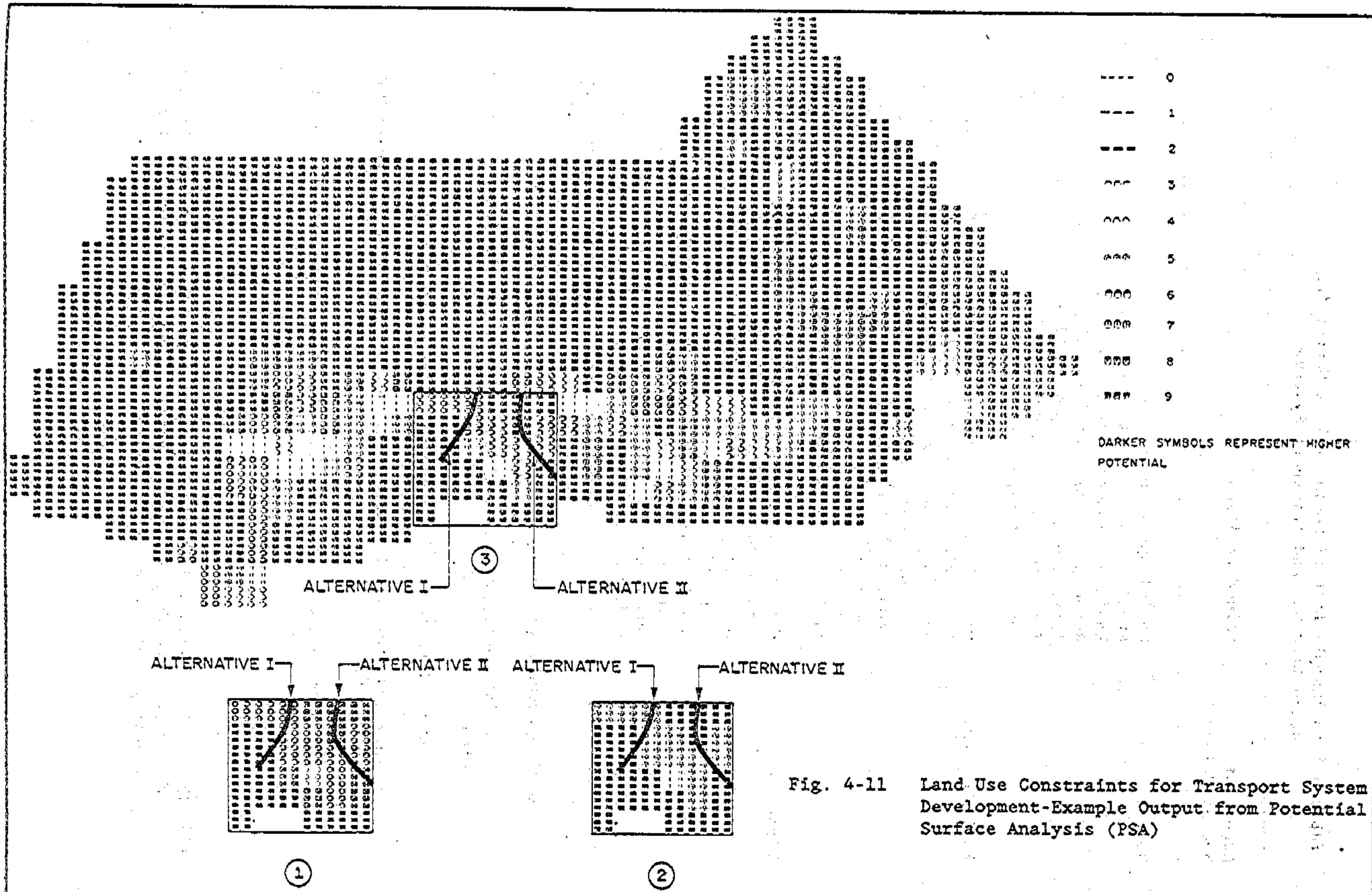


Fig. 4-11 Land Use Constraints for Transport System Development-Example Output from Potential Surface Analysis (PSA)

Table 4-6 An Example List of Social Values Concerning Urban Land Use and Transport Systems

Aspect of Social Values	Valued Entities
Social	Social opportunity Stability and security Equitable income distribution Reduced loss of useful housing Increased housing opportunities Increased job opportunities Public participation
Environmental	Clean Air, less noise, unpolluted water Pedestrian safety, reduced traffic conflicts Reduced property value depreciation due to highway construction Reduced through-traffic for residential area Increased amenities of natural and historic sites Fields and parks of easy access
Financial	Cost efficiency, effectiveness of public planning Maintenance of economic stability of society Low transportation costs, both capital and operating Encouragement of economic growth Reduced service costs for land development

[1]

Goal Statement (Example):

- Alleviate peak hour traffic concentration at the fringe of urban area.

- Improve link connectivity between area A and area B.

- Increase the road density to encourage urban development eastwards.

- Minimize environmental impacts and increase residential amenity.

[1] Kuranami, C. (1983) Multiple Objective Approach to The Optimization of Urban Land Use/Transport Systems, Unpublished Ph.D. Thesis, University of New South Wales, P. 25

Table 4-7 Transport Users' Interests

Transport User	Interests and Areas of Concern
Motorists	Better roads, more freeways, more parking areas, less congestion, cheaper petrol, less conflict with pedestrians.
Pedestrians	Traffic-free walking, wide, comfortable foot paths, less change of levels, more pedestrian priority crossings, undercover walking in harsh weather.
Cyclists	Exclusive cycleways, better sealing, cleaner air, better cycle parking facilities.
Public Transport Users	Frequent services, better access to stations, reliable services, more routes, safe and comfortable rides, cheaper fare, (for the disabled and elderly particularly) secured seats, lower steps, fewer transfers.
Shippers of Freight	Low shipment costs, reliable transportation services.

[2]

Objective Statement (Example):

- Achieve average traffic speed of 20 km/hr in city center and 40 km/hr in outer area.
- Achieve total length of distributors in the area at 4 km/km^2 in residential area.

[2] ibid, P26

PART 5:

Transport Demand Analysis

5.1 Introduction

Modelling Approach to Transport Demand Analysis

This part of the manual describes the transport demand forecasting techniques, especially the modelling approach known as 'four-step model', which provides a comprehensive estimate of future transport demand distributed over transport network. This method, however, requires a great deal of skilled manpower and modern technology based on computer application, but to improve the rationality of planning, it is recommended to apply this method as widely as possible, especially to those cities where the extent of population, study area and transport network is sufficiently large and the transport problems becoming an public issue.

This approach involves survey techniques called 'origin-destination (O-D) surveys' (See, Sec. 3.4) and the data are analyzed to give basic understanding of travel behaviours so that the future transport demand can be predicted in relation to future specification of land use and transport systems.

The detailed explanation of the theory and procedure of this modelling approach can be found later within this Part, but the basic steps in the modelling approach can be shown as follows:

1. O-D survey and analysis.
2. Obtain future land use pattern from land-use planning sector.
3. Estimate number of trips generated and attracted from each traffic zone.
4. Estimate the amount of generated and attracted trips for each origin and destination pair.
5. Estimate link volume of traffic on transport network.
6. Evaluate the balance between transport demand and the transport system, modify the future specification of land use/transport system. If it is not adequate then return to step 3.
7. Repeat until satisfactory plan is made.

Resource Requirements

Application of the proposed method requires a great deal of skilled man-power and modern technology based on computer applications. The time required for the experimental application of the modelling method to Chiang Mai was worked out in Table 5-1. According to the table, a total of 350 man-days were required. This is mostly an additional effort compared with existing process of planning. For the cities of different sizes the total time requirement was estimated as shown in Table 5-2. Both of the tables suggest that a substantial additional effort is required for the full-scale application of the quantitative approach. Then, the criteria for selecting cities where this endeavour can be justified need to be carefully worked out.

It is noted at this point, that a close examination of the Table reveals that items 1 to 3 consist of 87% of total man-days, and if this process is simplified the application becomes more economical. There is a possibility in this direction and the assessment of applicability must be made by keeping this point in mind.

Which Cities Require Modelling Approach

Planning for roads requires specification of the dimension of right of way. For this reason, it is preferable to apply some form of quantitative approach on almost all occasions. It is obvious that, however, smaller cities with one or two principal roads do not require, at least, computer based traffic assignment. The origin and destination pattern of these cities is fairly obvious and it may be possible to assume that most of the traffic is centered around the main trunk lines passing through the city. Manual assignment can be performed with reasonable accuracy for cities with two to three trunk lines. In another extreme case, such as in Bangkok, it is impossible to work out O-D pattern and to estimate traffic volume on road network without applying a sophisticated method such as the one introduced here. From this 'technical' point of view, a computer based approach seems to be required for medium to large cities with sufficiently complicated road network. Examination of road network patterns reveals that many of the regional cities are in this category. This could serve as a technical criterion for the judgment.

Another important view-point can be introduced from the evaluation of the extent of transport problems both at present and in the future. One of the most dominant urban transport problems is traffic congestion. Smaller cities could face temporary traffic jam due to stoppage resulting from road repair works traffic accidents, but the need for better network planning may not become public concern; it puts no pressing demand to local administrators to take action to solve the problem. From this 'administrative' point of view, the cities where traffic congestion is, or is becoming, a public issue deserve the detailed quantitative approach.

Alternative Approaches

Due to the resource availability, all of the cities may not be planned by the method applied in Chiang Mai Case Study, but a variety of simplifications has been proposed, such as trend analysis and the O-D matrix estimation technique from traffic counts. Details of these can be found in Part 6 : Alternative Approach to Demand Analysis.

Table 5-1 Man-Power Requirement of Quantitative Transport Demand Analysis - Case of Chiang Mai

Type of Work	Type of Manpower (man-day)				Total (%)
	Planner	Analyst	Key Puncher	Field Staff	
1. Person Trip Survey	10	-	-	260	270 (77)
2. Data Coding	-	4	25	-	29 (8)
3. Validation	-	5	-	-	5 (2)
4. Network Data Preparation	3	5	12	-	20 (6)
5. O-D Matrix Construction	5	14	-	-	19 (5)
6. Assignment	1	2	-	-	3 (1)
7. Evaluation	1	3	-	-	4 (1)
8. Presentation	20	33	37	260	350 (100)

N.B. (1) The application did not include modal split process.

(2) Besides the above listed data, the approach requires road side traffic counts, but it is not listed here since this data is also required by the non-quantitative approach.

Table 5-2 Manpower Requirement of Quantitative Approach by City Size - An Estimation

Approximate Population Size	Example City	Model Size		Manpower Requirement (man-day)
		Assumed #of Zones	#Links[1]	
Over 3 million	Bangkok	100	1500~2000	1,000-1,500
300,000	Chiang Mai	50	500- 900	300- 400
100,000	Ban Pong	20	100~ 150	150- 200
50,000	Mab-ta-put	10	50- 60	100- 120

[1] # of links include dummy links

5.2 Preliminary Analyses

Modelling approach requires preparatory analyses on collected data. There are three major areas where these preliminary analyses are required as listed below:

1. Construction of present O-D matrix;
2. Network representation; and
3. Socio-economic framework.

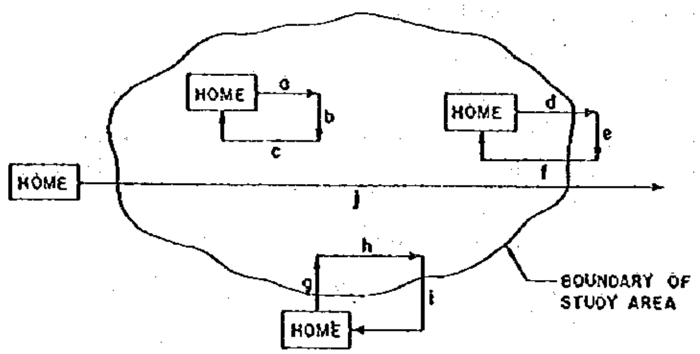
Each of the above items are elaborated in the following sections.

5.2.1 Construction of Present O-D Matrix

Types of Traffic Movements

From the diagram shown below (Fig. 5-1), it can be seen that types of traffic movements in reference to the boundary of the study area can be classified into four categories as follows:

- Internal trip represented by movements a, b, c, h;
- Internal-External trip as represented by movements d, f, g, i;
- External trip as represented by movement e; and
- Through traffic as represented by j.



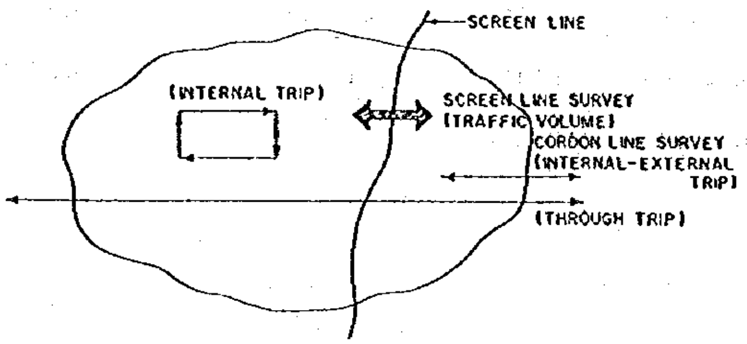


Figure 5-1 Types of Traffic Movements in Relation to Study Area

From the characteristics of traffic movement depicted above, the traffic survey has to be conducted in three separated categories to enable the coverage of traffic movement of different natures.

The principal objective of the traffic survey is to find out the origin and destination of the trips. Therefore, in the course of surveys, the data to be collected should preferably be on the trips occurring on the same day throughout the study area; such surveys must also be conducted in the working days of the week, for the volume of traffic is comparatively higher than that of the holidays.

Definition of O-D Matrix

O-D Matrix is the matrix representing trip distribution from zone i (= 1, 2, 3,..., n) to zone j (= 1, 2, 3,..., n). The general diagram of O-D Matrix is shown in Table 5-3.

Table 5-3 O-D Matrix Representation

Origin Zones	Destination Zones						Total
	1	2	....	j	....	n	
1	t_{11}	t_{12}	....	t_j	....	t_{1n}	G_1
2	t_{12}	t_{22}	....	t_{2j}	....	t_{2n}	G_2
.	.	.		.		.	.
.	.	.		.		.	.
.	.	.		.		.	.
.	.	.		.		.	.
.	.	.		.		.	.
i	t_{i2}	t_{i2}	....	t_{ij}	....	t_{in}	G_i
.	.	.		.		.	.
.	.	.		.		.	.
.	.	.		.		.	.
.	.	.		.		.	.
n	t_{n1}	t_{n2}	....	t_{nj}	....	t_{nn}	G_n
Total	A_1	A_2	....	A_j	....	A_n	T

From the table shown above we can see that t_{11} is the trip with the origin and destination in zone 1; t_{12} is the trip with the origin in zone 1 and destination in zone 2; and in the same manner, t_{ij} is the trip with the origin in zone i and the destination in zone j.

G_i is the trip generation of zone i, in this case, it is the summation of $t_{i1} \ldots t_{in}$ (i = 1, 2, 3,...,n).

A_j is the trip attraction of zone j, in this case, it is the summation of $t_{ij} \ldots t_{nj}$ (j = 1, 2, 3,..., n).

T is the total trip or the product of and can be shown mathematically as

$$\sum_{i=1}^{n} G_i \text{ or } \sum_{j=1}^{n} A_j$$

O-D Matrix and Types of Traffic Movements

Traffic movements defined as elements of O-D matrix possess origin-ends and destination-ends; these movements are often called 'trip interchanges', which can be classified into four categories in relation to the study area boundary.

1. Internal trip or Internal-Internal trip. the origin is inside the study area and the destination is also inside the study area.

2. Internal-External trip. the origin is outside the study area but the destination is inside the study area.

3. External-Internal trip. the origin is outside the study area but the destination is inside the study area.

4. External-External trip or Out-out trip. the origin is outside the study area and the destination is also outside the study area.

The traffic movements in these four categories can be integrated into an O-D Matrix in the manner shown in Table 5-4.

TABLE 5-4 Source of Survey Data in the Integration OF O-D Matrices

Origin Zones	Destination Zones	
	Internal	External
Internal	II (Home Interview)	IE (Home Interview)
External	EI (Cordon Survey)	EE (Cordon Survey)

O-D Matrix and the Summation of Data Collected Through Interview Survey and Cordon Line Survey

As was mentioned earlier, the objective of conducting the interview survey is to find out the internal trips; and the cordon O-D survey, to find out the External-Internal and through trips. A complete O-D matrix must be constructed by taking the survey results of both categories into consideration. In many cases during the course of the interview survey, informations or data on Internal-External and External-Internal trips may be also received, for example, when asked, the interviewees of home interview survey may give their answers that their first trip was a journey to work from his home (in the study area) to office (outside the area) and in the evening he returned home from his office; this latter trip may also be counted at Cordon O-D Survey. In compilation of the data collected from these two sets of survey, External-Internal trips taken from the interview survey have to be deleted to prevent double counting of the same trip within O-D matrix.

In summary :-

- to find out the number of Internal-Internal and Internal-External trips. Home Interview (Person Trip) survey is applied; while,

- to find out the number of Out-in and Out-out trips, the Cordon O-D Survey is applied. (Table 5-5)

Table 5-5 Types of O-D Surveys and Their Relation to the Construction of O-D Matrix

Type of Survey	Survey Method	Purpose of Survey
Person Trip Survey (or Car Owner O-D Survey)	Interview at vehicle owner's/tripmaker's home	To obtain movements of internal trips
Cordon O-D Survey (Additional)	Interview drivers by road sides	To obtain movements of Internal-External trips and through trips
	Traffic volume counting	To obtain total traffic volume passing on cordon lines and to calculate expansion factors
Screen line survey	Traffic volume counting	To verify results of traffic assignments on present road network

Occupancy Rates

One of the problems encountered in the compilation of the data taken from the person trip survey and cordon O-D survey, is that, if the Home Interview Survey intends to obtain traffic movements in person trip unit, the collected data cannot be combined with the number of vehicular trips taken from the Cordon O-D Survey as the dimensions of the trips are not in the same unit. Conversion of the unit from person trips to vehicular trips must first be made through the application of the 'occupancy rates'.

An occupancy rate is the average number of passengers each mode of transport accommodates in an ordinary situation. The table 5-6 shows the average occupancy rates used in the Chiang Mai case study.

Table 5-6 Average Occupancy Rate

(Passengers/Vehicle)

Mode of Transport	Occupancy Rate
Passenger Car	2.25
Taxi	2.71
Mini Bus	9.0
Bus	20.0
Light Truck (Pick Up)	-
Medium (6-wheel)	-
Heavy Truck (Ten-wheel)	-
Motorcycle	1.37
Bicycle	-

(Note : The figures are tabulated based on the observation conducted in Chiang Mai, 1985)

Expansion Factors

In the construction of O-D Matrix, there are two sets of expansion factors to be employed for Home Interview Survey and Cordon Line Survey respectively:

Expansion factors for interview survey. Assuming that the sampling rate is 10%, in the most simple case, the expansion factor will be

$$\frac{100\%}{\text{Sampling Rate}} = \frac{100\%}{10\%} = 10$$

In many cases, collection of data may falls short of the specified sampling rate. For example, the collection of data in traffic zone 1 may be 9%; while in traffic zone 2, 12%.

In case of each zone having different sampling rate, expansion factor of ij element (F_{ij}) is calculated as:

$$Fij = \sqrt{\frac{Ti}{Ri} \cdot \frac{Tj}{Rj}}$$

where,

R_i = sampling rate of zone i
R_j = sampling rate of zone j
T_i = total sample of zone i
T_j = total sample of zone j

Expansion factors for cordon O-D survey. To find out expansion factor of cordon O-D survey, is a simpler procedure than that of the interview survey, i.e.

$$\text{Expansion Factor} = \frac{\text{(Total No. of Vehicles Passing) (The Cordon Line Check Point)}}{\text{(Total No. of Interviewed) (Vehicles)}}$$

Construction of O-D Matrices

In many cases, O-D matrices are constructed in the vehicular trip unit. The process of constructing daily vehicular trip O-D matrix from Home Interview Survey and Cordon O-D survey can be shown below:

1. Construct person-trip O-D matrices for different types of transport mode. Each of the matrices is expanded by applying appropriate expansion factor.

   In mathematical notation, number of observed person trips between origin i and zone j using transport mode m can be expressed as $t'_{(m)ij}$. The process of expansion can be described as:

   $$t_{(m)ij} = t'_{(m)ij} \cdot f_{ij}$$

   where, $t_{(m)ij}$ = expanded trip between i and j for mode m; and
   f_{ij} = expansion factor for ij element of the O-D matrix.

2. Occupancy rate of each mode is applied to the respective O-D matrix to obtain daily vehicular-trip O-D matrices for all modes. These matrices represent Internal-Internal movements. By denoting r_m for the occupancy rate of mode m, number of vehicular trips between zone i and j for mode m ($T'_{(m)ij}$) can be obtained by:

   $$T'_{(m)ij} = t'_{(m)ij}/r_m$$

3. Cordon O-D Survey can be used to construct daily vehicular-trip O-D matrices by applying appropriate expansion factors. The matrices constructed here represent Internal-External, External-Internal and External-External movements.

4. The matrices in 2 and 3 are combined for the same transport modes.

5. Apply passenger car unit (PCU) rates to combine different modes of vehicular O-D matrices into single PCU - O-D matrix. Mathematically this process can be shown as follows:

   $$T_{ij} = \sum_m T'_{(m)ij} \cdot U_m$$

where T_{ij} = number of trips between i and j in PCU.

$T'_{(m)ij}$ = number of vehicular trips between i and j by mode m.

U_m = passenger car unit for mode m. (See Table 5-7 for example PCU rates applied for a transport study in Chiang Mai).

TABLE 5-7 Coefficient of Passenger Car Units (PCU)

Type of Vehicle	PCU Conversion Factor			
	Urban	Rural	Roundabout	Signalized Intersection
Passenger Car Taxi Truck (4 wheels)	1.00	1.00	1.00	1.00
Motor-cycle Motorcycle and any movable object	0.75	1.00	0.75	0.33
Medium Truck (6 wheels)	2.00	3.00	2.80	1.75
Heavy Truck Bus/Coach Trainer	3.00	3.00	2.80	2.25
Bicycle	0.33	0.50	0.50	0.20

(Source : Feasibility Study for Regional Cities Development, April 1983; Volume 2 - Chiang Mai)

Matrix Adjustment by Screen Line Survey

The O-D matrix constructed by using interview survey does not necessarily reproduce the traffic movement of the whole population due to various factors such as sampling and expansion errors.

The result of a screen-line survey is often used to 'adjust' the O-D matrix to ensure that the observed traffic volume of given cross-section of the road network is consistent with the total amount of O-D desire lines crossing that screen-line. The following procedure may be adopted to perform this adjustment.

1. Determine the O-D pairs that are likely to cross each of the traffic count studies along the screen-line.

2. Factor all the relevant O-D traffic volumes so as to equal the observed counts of respective stations.

3. Repeat the above process until all O-D volume are adjusted.

Alternative to the adjustment by a screen-line survey is the use of the matrix estimation theory explained in Section 6.3.

The process explained so far, is summarized in a flow diagram shown in Figure 5-2.

The existing levels of trip generation and trip attraction can be obtained by summarizing columns and rows of the O-D matrix, i.e.

$$G_i = \sum_j t_{ij}$$

$$A_j = \sum_j t_{ij}$$

where, G_i is the total of number of trips (PCU) generated from zone i

A_j is the total of number of trips (PCU) attracted to zone j

5.2.2 Network Representation

Traffic Zones and Zone Centroids

Traffic zones are the aggregated unit of urban activities. The modeled traffic is considered to be generated from, and attracted to, the zone centroids. A zone centroid is a point within each traffic zone, and is chosen so as to represent the center of land use activities. The exact location of the centroid is not very important, but its relation to the transport network gives significant influence to the result of succeeding network simulation.

Link and Node Data

In the network simulation method, highway network is represented by 'links' and 'nodes'. In general, a link is a representation of a road segment delineated by intersections, and the intersections are depicted as 'nodes'. There are also 'centroid nodes' which represent the concentration of population and various land use activities where traffic is generated and attracted. These centroid nodes are connected to the network, often, by using a 'dummy link' which has no corresponding physical dimension in actual road network. An ordinary link has a set of attributes such as link length, zero flow travel speed and travel time, and link capacity. An example of prepared link data is shown in Table 5-8.

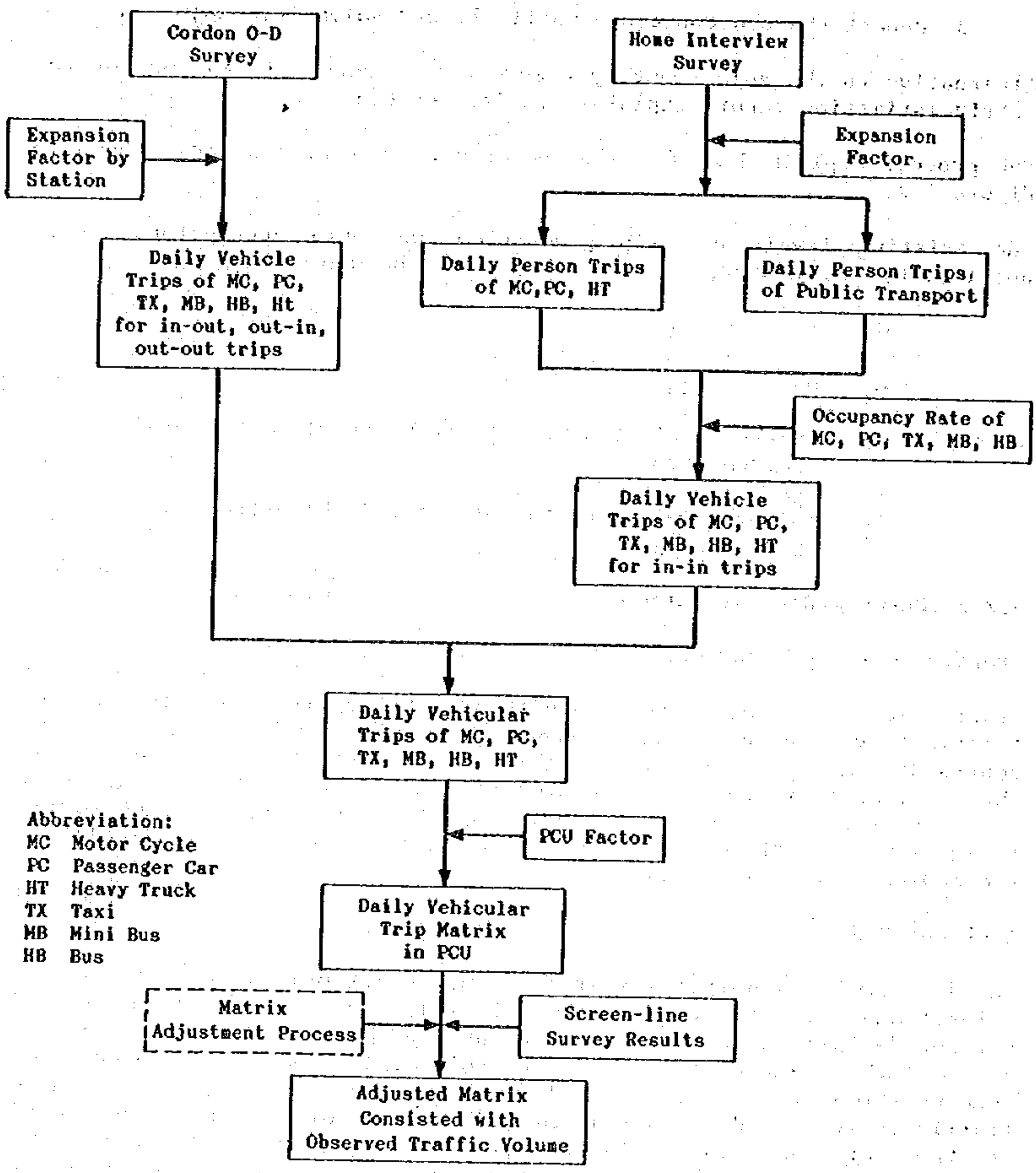


Fig. 5-2 Process of Constructing Present O.D. Matrix

TABLE 5-8 Example link Data Set

LINK NO.	NODE FROM	TO	LINK TIME	LINK LGTH	LINK SPEED	LINK CAP	CAP* CLS
100	61	130	1.7	1.1	38.	799.	3
101	61	196	.6	.6	51.	1200.	6
102	61	200	.3	.3	60.	1200.	6
103	61	201	.5	.4	48.	1200.	3
104	62	12	1.0	.1	6.	0.	1
105	62	196	.4	.3	45.	1200.	6
106	62	198	.2	.2	60.	1200.	6
107	63	13	1.0	.1	6.	0.	1
108	63	172	.2	.2	60.	1599.	6
109	63	173	1.1	.6	38.	799.	3
110	64	14	1.0	.1	6.	0.	1
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

* See Table for capacity class coding.

Link lengths are measured on the map along actual road alignments. Link speed, capacity and travel time, together with capacity class determine the Q/V relation which is used to account for the congestion effect in 'capacity restrained assignment'. Zero flow travel time is used for 'all-or nothing' assignment in which all the traffic between two zones are assigned on the shortest paths (often in terms of travel time).

Numbering of nodes should be systematic to distinguish centroid nodes from the rest of the nodes. Centroid nodes are numbered according to the zone number; e.g. centroid node 1 for traffic zone 1, centroid node 2 for traffic zone 2 etc. Intersection node should be started from, say 100 (for the network whose traffic zones are less than 100), or 1000. Sample network and numbering system is shown in Fig. 5-3 taking Chiang Mai as an example.

Q/V Curves

A Q/V curve shows the relationship between the number of vehicles (Quantity) and speeds (Velocity) maintained on each road.

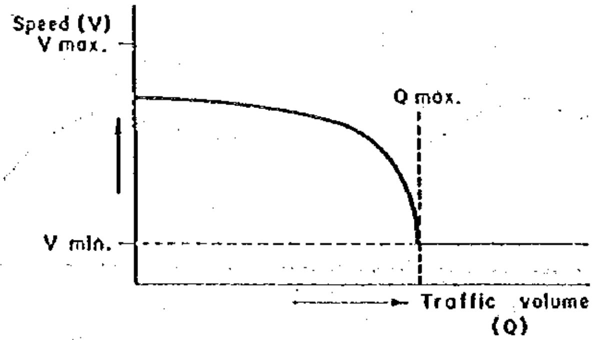


Figure 5-4 Q/V Curve in Network Analysis

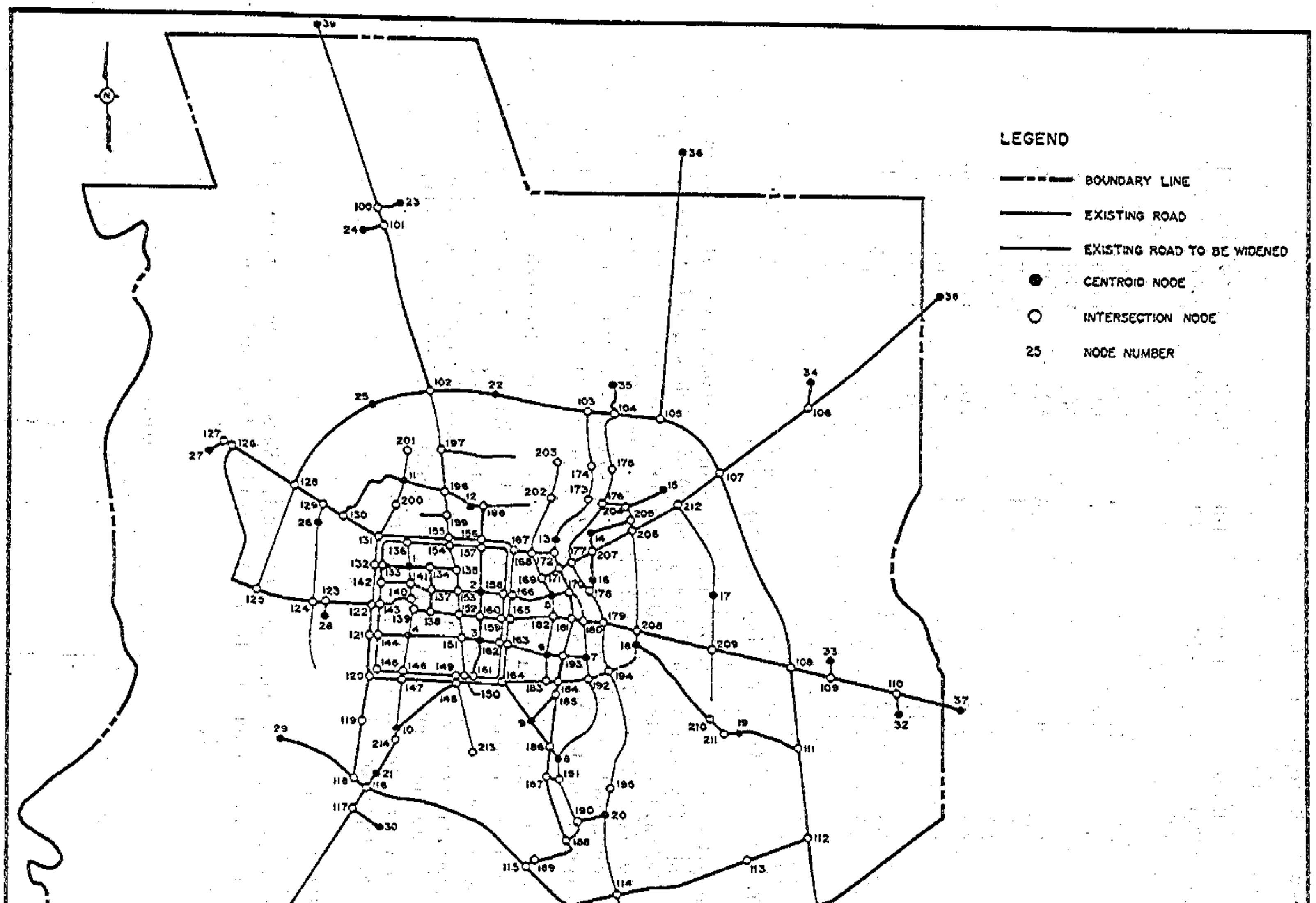


Fig. 5-3 TRAFFIC ASSIGNMENT NETWORK EXAMPLE (CHIANG MAI)

The determination of the Q/V relation is an important factor in the process of traffic assignment analysis. They are categorized into different orders depending on road widths and frontage land use conditions.

For Chiang Mai Case Study, the Q/V relations are categorized as follows:

Existing Roads:

Category #1: for roads having surface width under 6 meters;

Category #2: same dimension as #1 but better frontage condition;

Category #3: for road having surface width from 6-11 meters, with relatively extensive frontage development;

Category #4: for road having surface width from 7-12 meters, with relatively low frontage development. They are mainly intercity highways or urban roads with relatively wide road surface and few traffic problems; and

Category #5: for roads having surface width over 12 meters..

In the case of the existing link specification in Chiang Mai, the maximum category is set at #3.

Future Roads:

Road categories prescribed in the future transport plan of Chiang Mai (classified into type "A" to type "E" in the General Plan) corresponded to category #3 to category #5 as follows:

CATEGORY #3, i.e. Types "A" & "B".
CATEGORY #4, i.e. Types "C" & "D".
CATEGORY #5, i.e. Type "E"

Table 5-9 summarizes the Q/V classification used in the Chiang Mai Study.

Table 5-9 Example Q/V Classification used in the Traffic Assignment in Chiang Mai

Category #	Qmax (PCU/direction/hr)	Vmax (Kph)	Vmin (Kph)
1	800	40	4-8
2	1200	50	"
3	1600	60	"
4	3600	80	"
5	5400	80	"

(*Vmin are changed randomly between 4-8 km/hr. by the computer program used in the case study)

In a more general case, Vmax can be set by referring to official speed limits, and Qmax can be set by various traffic capacity studies. Alternatively, Qmax may be established by direct observation of volume-speed relation as shown in Fig. 5-5. This type of observation can be done by using an automatic classification recorder introduced in Sec. 4.1.2.

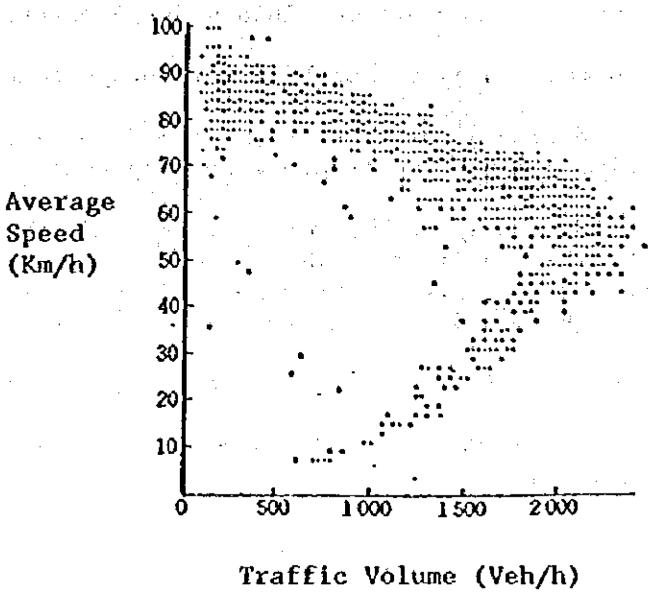


Figure 5-5 Volume-Speed Relation
(on Tokyo Metropolitan Expressway - JITE (1984) Traffic Engineering Handbook, Japan Institute of Traffic Engineers, P.143.)

5.2.3 Socio-Economic Framework

Socio-economic indices necessary for transport demand analysis are prepared based on the information obtained from Socio-Economic Research Sector and Land Use Planning Sector. Some other sources such as census and various registration records may be necessary for certain occasions.

The required items of data vary according to the modelling strategies of trip generation and trip distribution analysis, but the most fundamental data that can be collected and forecasted for transport planning in the preparation of General Plan, may be listed below. The uniqueness of this stage is that each of the listed item should be tabulated for every traffic zone separately. The relevant sectors mentioned above may not be concerned about the traffic zones. In the consideration of socio-economic framework the transport planner should deal with the following three aspects:

(1) Data source;
(2) Projection of framework; and
(3) Spatial distribution over traffic zones.

Data Source

Population. Socio-Economic Research Sector conducts primary, field survey i.e. household interview survey. Data on population are also available from other sources such as registration statistics or census, therefore, when primary survey has not been conducted or incomplete the latter sources are also considered. Between the registration statistics and census data the latter are more reliable than the former because births are usually registered at the place of birth rather than the place of residence. The breakdown of population is sometimes important especially the number of workers and students who constitute the major part of peak hour traffic.

Employment. Socio-Economic Research Sector conducts commercial and industrial establishment survey. Department of Labour produced employment statistics in Industrial Labour Survey (1978) that can be used as reference data if necessary. This information becomes important in travel demand analysis, particularly in trip-attraction modelling process. Classification by types of industry - i.e. primary, secondary and tertiary is recommended.

Car-Ownership. Municipal based car ownership is available from Vehicle Registration Record, but distribution over traffic zones is not immediately known to the transport planner[1]. This can be estimated by using the result of household interview survey along with the average income levels of each zone. The obtained information can be used to increase the accuracy of trip generation modelling.

Projection of Future Level of Socio-Economic Indices

The detailed projection methods of demographic data (i.e. population related data) are explained in VOLUME III: SOCIO-ECONOMIC ANALYSIS MANUAL. Various analytical techniques are available but the process of the forecast should also change according to the degree of government intervention on urban development. SSTR Study, for example, identifies the following three scenarios[2]:

1) Maximum government influence;
2) Minimum government influence; and
3) Managed growth.

The first scenario assumes that the Government's development targets are all achieved. The second scenario puts emphasis on the city growth driver by market forces, and third scenario takes the middle of the first and the second scenarios.

Depending on ench scenario the forecasting method of population and employment is changed. The main difference is in the assumptions made to the growth rates. Fig. 5-6 summarizes the population estimation forecasts of this study under the different growth scenarios.

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[1] But zonal distribution can be tabulated from the original registration records if sufficient time is available.

[2] HFA (1985), Population and Employment Forecasts, Internal Working Paper No. 5. Metropolitan Bangkok Short Term Urban Transport Review.

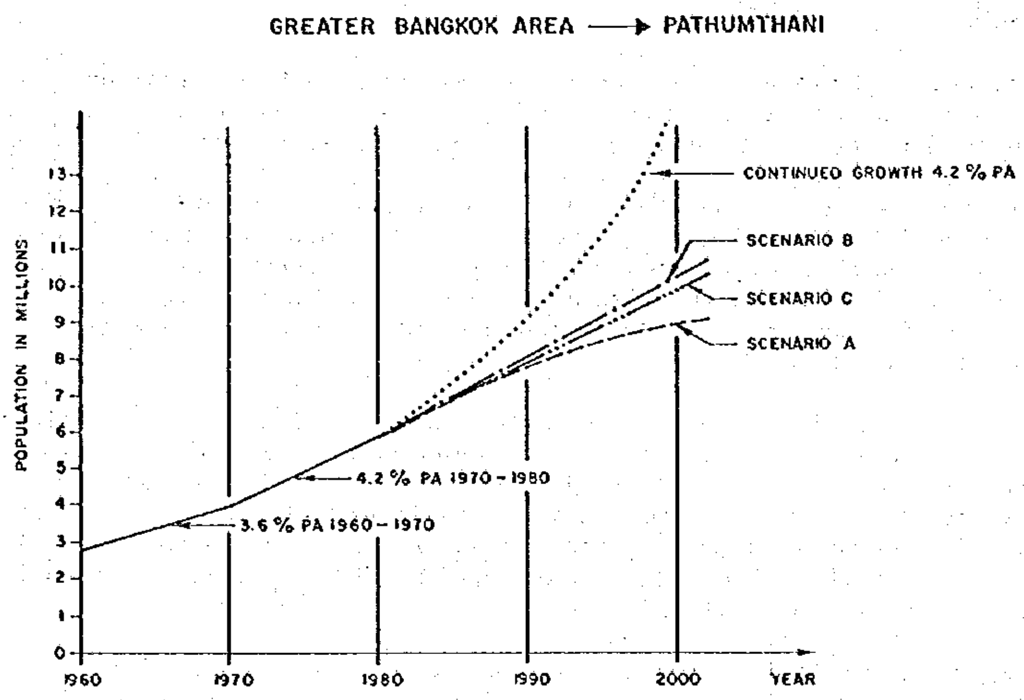

Figure 5-6 Population Growth Under Different Scenario
(Source: STTR Working Paper)

Projection of car ownership. The projection of car ownership often utilizes the income level of households as a dominant factor. Fig. 5-7 was established by the STTR Study and this relation was used to project the vehicle ownership of traffic zones by substituting the future level of income to the income scale of the above Figure. Future income, in turn, is estimated by using existing income level and the growth rates established by referring to various published statistics of national GDP per capita.

In many cities of industrialized countries, however, car ownership is dependent not only on income levels but also other factors such as public transport availability and parking space availability. For those cities the number of cars per capita is higher in rural areas than in urbanized areas regardless of the fact that the income level might be higher in the latter area. Thus, more detailed analysis of car ownership should take those factors into consideration.

Spatial Distribution over Traffic Zones

Traffic zone boundaries are usually not the same as administrative boundaries, but the transport planner has to estimate most of the socio-economic indices over traffic zones rather than the study area as a whole. As it has been mentioned in the previous sections, the tabulation of existing indices and the projected figures should take place zone by zone, but, if this is not the case the area-wide population or employment level have to be 'allocated' over traffic zones.

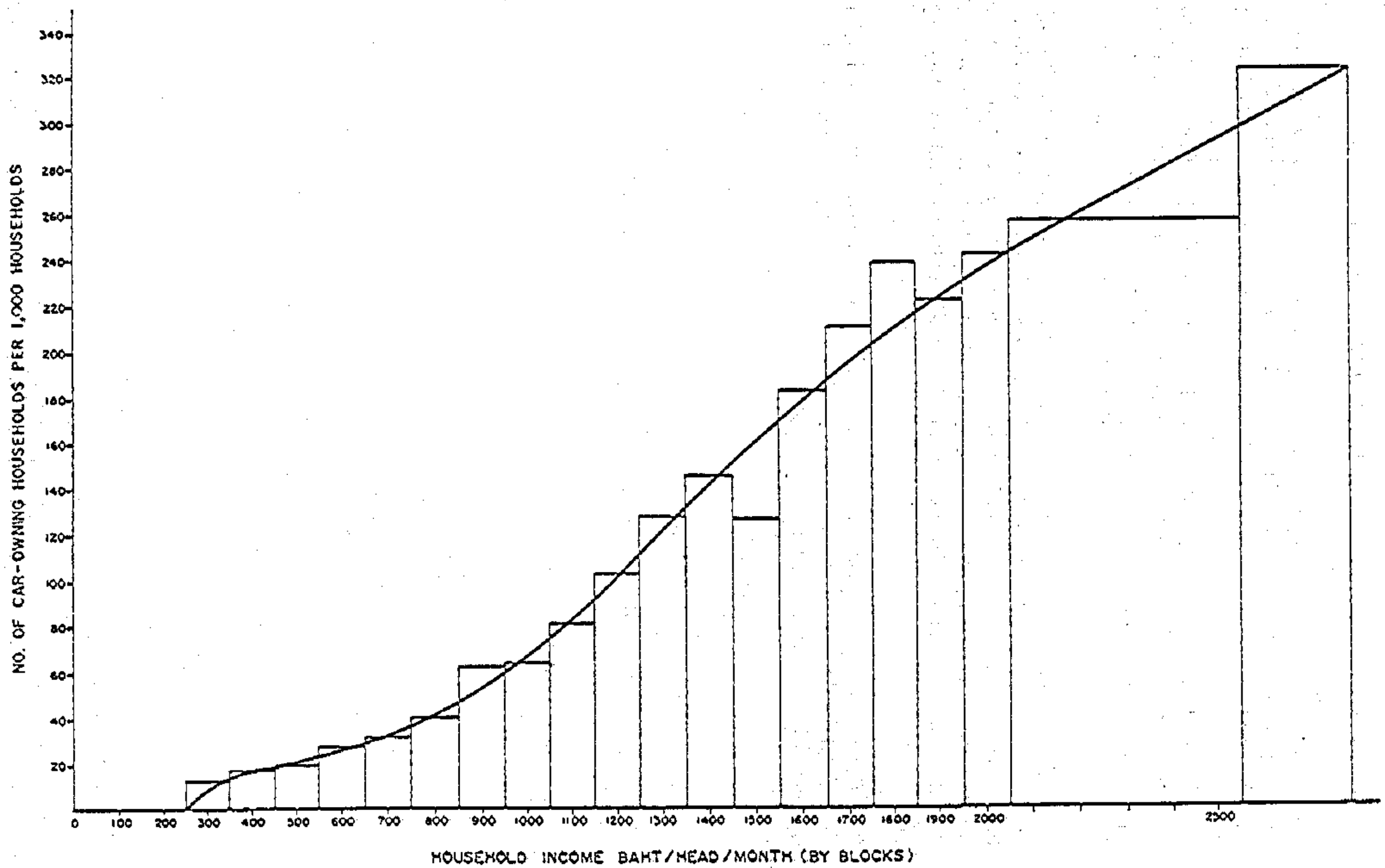

Fig. 5-7 Relationship between Income and Car-Owning Households (by Blocks)

Land use plan in a General Plan is an example from which the spatial distribution of population and employment have to be estimated prior to the transport demand forecasting.

Simple Method of Population and Employment Allocation

A simple method for this purpose may be introduced by assuming that future total population and employment levels of the study area are available, the allocation into traffic zones can be made as follows:

1. Tabulate the area of different land uses (c.f. Fig. 5-8 for an example as land use plan) for each traffic zone. Denote by $a_{i(n)}$ for the area of land use type n in traffic zone i. (c.f. Fig. 5-9 for traffic zone boundary)

2. Establish weighting system in terms of the degree (weighting) of contribution to residential population and number of employments. The weighting system may be established by analyzing existing density and land use pattern. Denote these weighting p_n and e_n for residential population and employment by land use type n respectively.

3. Calculate the proportional factors for residential population and employment for each traffic zone. Denote these by PF_i and EF_i which are defined by:

$$PF_i = \sum_n a_{i(n)} \cdot p_n$$

$$EF_i = \sum_n a_{i(n)} \cdot e_n$$

4. Allocate the total population and employment by using the following formula:

$$P_i = P \cdot \frac{PF_i}{\Sigma PF_i}$$

$$E_i = E \cdot \frac{PF_i}{\Sigma PE_i}$$

where, P_i = Population in zone i
E_i = Employment in zone i
P = Future total population
E = Future total employment

Adjustment may have to be made to reflect existing population and employment levels.

5.3 Trip Generation

The purpose of the trip generation process is to estimate the number of trips produced and attracted to each traffic zone. The unit of the analysis is either in person trips or vehicular trips, though, the latter is more frequently used in highway network planning. A trip has

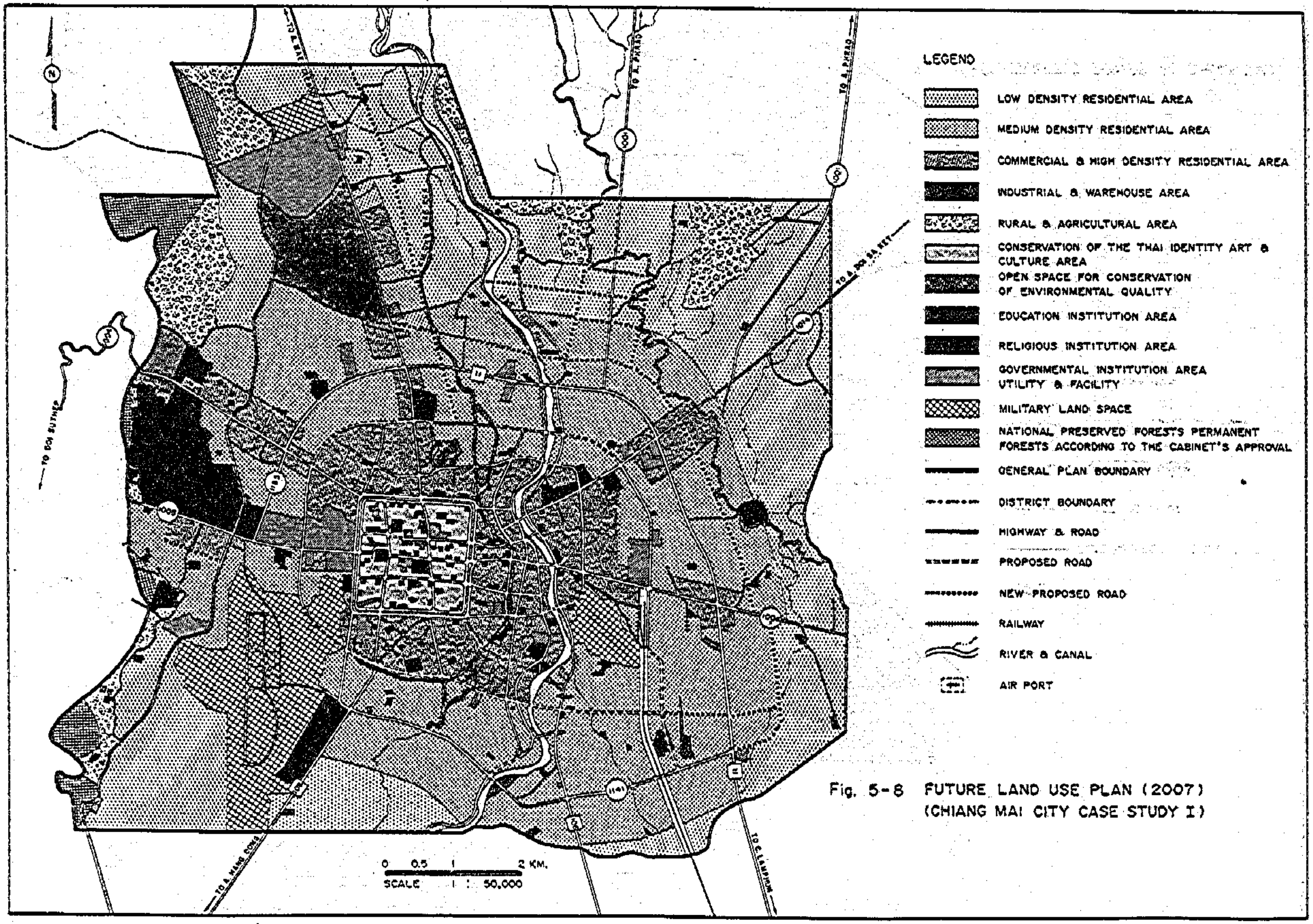

Fig. 5-8 FUTURE LAND USE PLAN (2007)
(CHIANG MAI CITY CASE STUDY I)

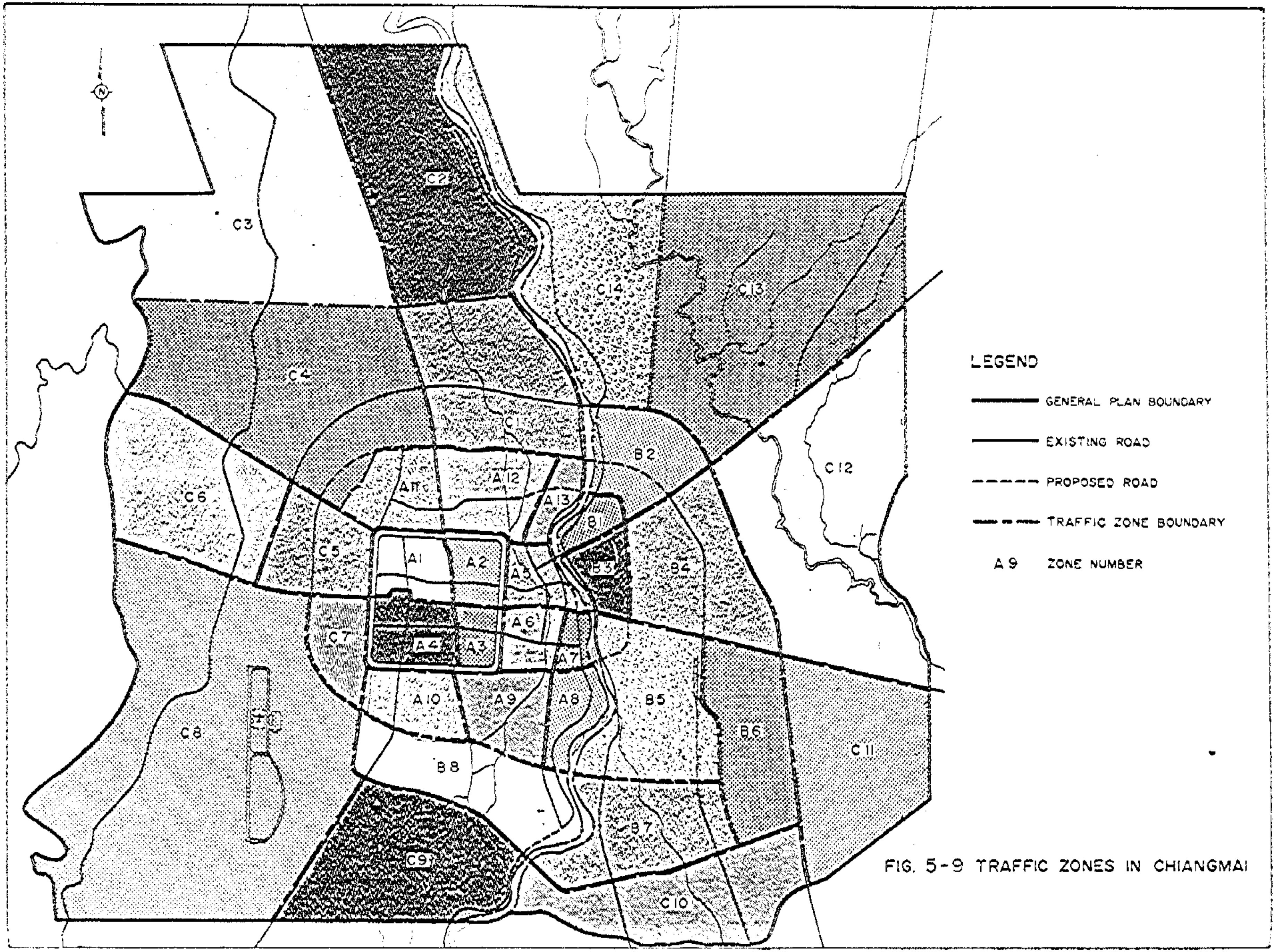

FIG. 5-9 TRAFFIC ZONES IN CHIANGMAI

two 'trip ends': one is the 'production' end (origin), and the other, 'attraction' end (destination). Eighty to ninety percent of production ends terminate usually in residential area (i.e. Home-and the other ends are connected to other various types of land use such as offices and schools.

Factors Influencing Trip Generation[1]

Land use type is a convenient way of classifying trip generating activities. Different uses of land produce different degrees of trip generation, e.g. land used for shops and offices could generate more trips than land use for open space. Similarly, different intensities give different traffic generation characteristics: for example, one acre of residential land developed at a high density would produce more total person movements than one acre of land developed for residential purposes at a low density. On the other hand, the low-density residential area occupied by fewer and probably more expensive dwellings could well produce more private motor vehicle trips than the high-density residential area, where car-ownership is very low.

Motor vehicle ownership. The ability to satisfy travel demand is affected by the availability of alternative means of transport and the adequacy of the highway system. Motor vehicle ownership, or the number of vehicles available for use by each household, has been found to have a significant influence on trip generation.

Family size. A relationship exists between the frequency of trips and family size.

Family income. The ability to pay for a journey affects the number of trips generated by a household. Families with a high income can generally afford to satisfy more of their travel demands than low-income families.

Age structure. This factor is often taken into consideration in trip generation analysis on the basis that different age groups produce different movement demand and characteristics.

Occupational composition. Different types of occupation could lead to different travel demand, e.g. blue-collar workers, may produce different travel characteristics from white-collar workers.

There are two basic methods in trip generation forecasts: trip rate method and regression analysis method, both of which are explained below.

5.3.1 Trip Rate Method

This method is the simplest method in the estimation of future trip generation, but a considerable amount of data is needed to tabulate reliable trip rates.

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[1] This part is based on JICA (1984) 'Comprehensive Urban Transportation Planning, PP IV-4 -- -5

Different types of trip rates can be established; for example:

1. # of trips/land use (or floor area); and
2. # of trips/person (or household).

The first method is called land-use ratio method and the second method is called person trip ratio method.

Land Use Ratio Method

This method applies the number of trips generated from different land use categories. These rates are multiplied by the future amount of respective land use to estimate trip production and attraction.

Cordon Survey method may be applied to a specific (and uniform) portion of land use and all the traffic leaving and arriving the area are recorded; mode of transport is surveyed at the same time. Morning peak hours, for example from 7:00 am to 9:00 am, may be surveyed to obtain peak-hour trip generation and attraction rates. Measurement of the area is performed either on actual site or on the map, and the trip generation rates per unit area are tabulated for estimation purposes.

Alternatively, an interview survey may be conducted, in which people within particular zone or establishment are sampled and asked about their travel behaviours. This method is useful for residential areas and offices where statistical treatment to the sampled data is tractable. For other types of land use such as market places and commercial establishments, the Cordon Survey is more useful. Example of trip rates by land use activity categories are shown in Table 5-10.

Table 5-10 Example of Trip Generation and Attraction Rates by Land Use Activities (Japanese Example)

(trips per 100m^2 - floor area)

Type of Land Use	Trip Purposes: Home to Work	Home to School	Home	Shop	Social	Business
Trip Generation:						
Office	0.12	0.07	14.30	2.43	2.61	9.57
Education	0.07	0.05	20.09	0.86	1.19	0.64
Retail	0.29	0.19	65.68	10.46	5.52	12.02
Resident	2.49	1.54	0.61	1.96	2.11	0.77
Medicine	0.35	0.10	15.24	3.33	2.44	2.15
Factory*	0.01	0.01	0.92	0.10	0.06	0.35
Trip Attraction:						
Office	14.24	0.06	0.18	0.09	3.49	11.88
Education	1.67	17.77	0.07	0.02	2.73	1.52
Retail	4.92	0.03	1.84	71.77	3.95	11.54

Resident	0.02	0.01	8.20	0.15	0.68	0.40
Medicine	2.39	0.03	0.26	0.10	19.21	1.86
Factory*	0.95	0.01	0.02	0.01	0.05	0.45

* Trip rates for factory is measured in land area (100 m^2)[1]

Another possible method for establishing land-use-related trip rates, is to use the results from the area-wide person trip survey and relate them to the land use statistics established by the socio-economic surveys. Number of trips that originates from or is destined for specific land use types is correlated to the amount of that land use within the study area. The land use can be measured either by floor area or land area.

Person Trip Rate Method

This is vased on a similar principle as the land use ratio method. The number of trips generated from each household are tabulated by using Person-Trip Survey results. This method is best suited for the estimation of trip generation rather than trip attraction because the future level of population by traffic zone is usually available.

The assumption underlying this method is that the average number of trips per person per day remains the same from person to person, and does not change over time. Therefore, refinement can be made by including age structure, motor vehicle ownership and income levels in the trip rate tabulation and the population forecasted.

5.3.2 Regression Analysis Method

Linear multiple-regression analysis is based on the most widely used technique in trip generation modelling. Using the person-trip survey results and separately collected socio-economic indices, the regression equation is calibrated by the formulae shown below.

$$T_i = b_o + b_1X_{1i} +, \ldots, + b_nX_{ni}$$

where, T_i = number of trips produced from (attracted to) zone i

X_{ni} = n-th socio-economic characteristics of zone i

b_n = regression co-efficient

Example of Regression Models

A JICA Study in Bangkok[2] employed the regression analysis approach to trip generation and attraction by seven different vehicle types. The

[1] ibid, PP IV-6, 7

[2] JICA (1986) Feasibility Study on New Krungthep Bridge Construction and Thonburi Road Extension: Progress Report II Japan International Cooperation Agency and PWD, MOI.

explanatory variables included were: population X_1, employment X_2, car ownership X_3 and number of students X_4. The regression formula adopted are shown below.

$$P_i^{(n)} = a^{(n)} + b_1^{(n)} X_{1i} + b_2^{(n)} X_{2i} + b_3^{(n)} X_{3i} + b_4^{(n)} X_{4i}$$

$$A_j^{(n)} = c^{(n)} + d_1^{(n)} X_{1j} + d_2^{(n)} X_{2j} + d_3^{(n)} X_{3j} + d_4^{(n)} X_{4j}$$

where, $P_i^{(n)}$ = Number of trips produced in zone i for vehicle type n.

$A_j^{(n)}$ = Number of trips attracted to zone j for vehicle type n.

$a^{(n)}$, $c^{(n)}$ = Regression constants

$b_m^{(n)}$, $d_m^{(n)}$ = Regression co-efficients

X_{mi} = m-th socio-economic factor in production zone i

X_{mj} = m-th socio-economic factor in attraction zone j

where, m = 1 population
2 employment
3 number of registered vehicles
4 number of students

Table 5-11 shows the calibration results for morning peak-hour trip generation and attraction.

Table 5-11 Example Trip Generation Model

Vehicle Type	P/A*	Population b_1	Employment b_2	Car Ownership b_3	No. of student b_4	Constant a,c	Correlation Coefficient R^2
Passenger Car	P	-	-	149.4	-	223.3	82.3
	A	-	23.17	-	-	219.4	69.4
Taxi	P	2.112	-	17.45	-	70.1	70.9
	A	-	6.794	7.798	-	69.4	68.3
Light Bus	P	0.057	-	-	2.052	10.2	45.8
	A	0.145	-	-	1.686	8.7	41.8
Heavy Bus	P	-	0.391	-	3.791	3.1	58.3
	A	-	0.064	-	2.757	18.5	41.9
Light Truck	P	-	0.782	-	5.437	78.5	44.5
	A	-	1.115	-	4.093	84.7	37.3
Heavy Truck	P	-	0.085	-	0.573	0.6	33.2
	A	-	0.143	-	0.268	3.8	22.7
Motorcycle	P	2.045	-	39.37	-	211.9	55.9
	A	-	13.767	-	-	138.0	64.2

(*P: Production, A: Attraction)

The estimation result for bus and truck trips does not seem to be satisfactory. The reason for the relatively low R^2's may be attributed to various factors such as:

- lack of sufficient socio-economic factors in the model; and

- model was stratified by mode of transport, but no variable indicating their ownership level was incorporated.

The calibrated models are used to predict future levels of trip generation. The use of estimated equations, however, results in future trip production/attraction levels being estimated as <u>lower</u> than present levels. To avoid this unfavorable situation, the following method can be applied.

1. Substitute present levels of explanatory variables into the calibrated equation; and obtain present level of trip production/attraction.

2. Substitute future levels of explanatory variables into the equation, and obtain future level of trip production/attraction.

3. Take the increment of the production/attraction levels which were calculated by using the results in steps 1 and 2, and add this value to the existing trip production/attraction level.

The above process is shown in Figure 5-10.

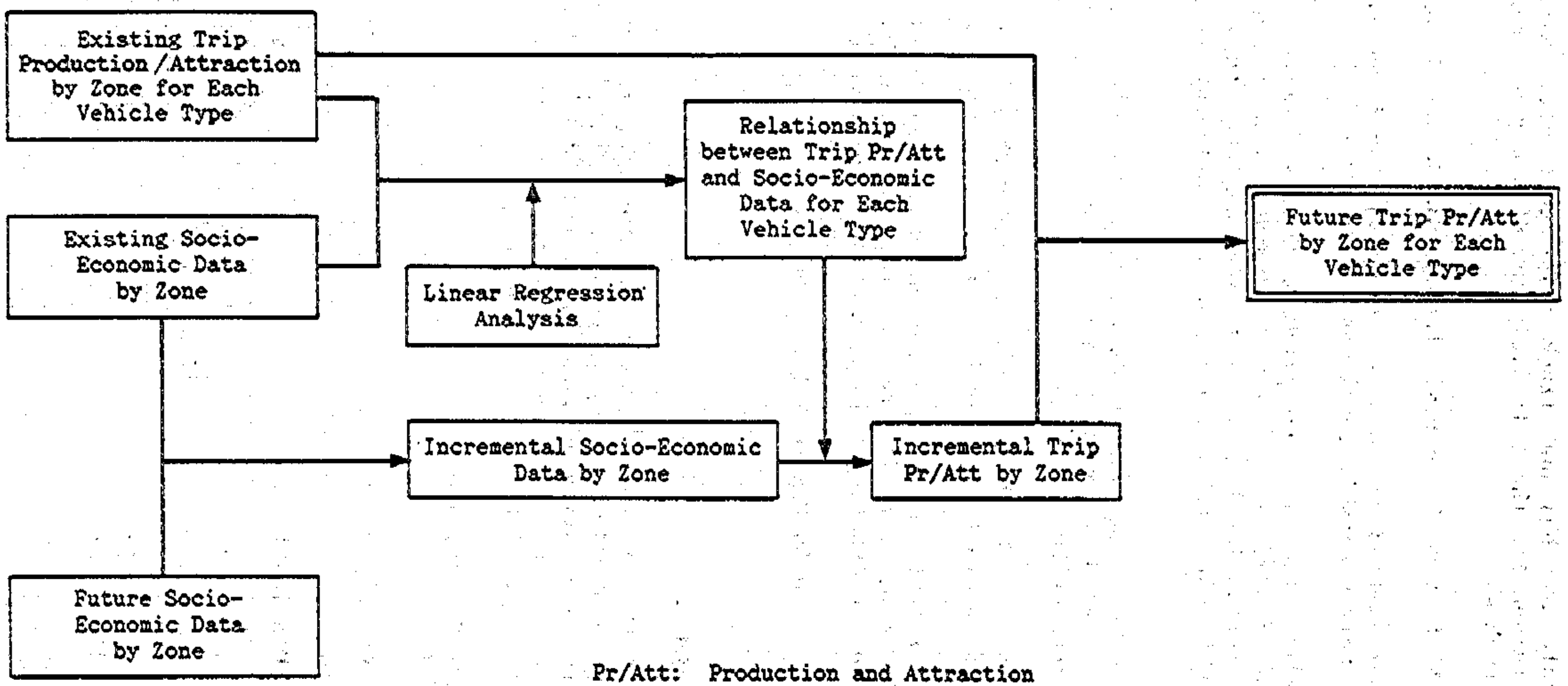
5.4 <u>Trip Distribution</u>

Trip distribution is the process of estimating inter-zonal trips from given generation and attraction levels as control totals; i.e. it is a process of estimating O-D matrix element x_{ij}'s from P_i's and A_j's in Table 5-12. During the past two decades various methods have been developed, but they tend to fall into two main groups:

1. Growth Factor Method; and
2. Gravity Model.

Table 5-12 Concept of Trip Distribution

Origin Zone	Destination Zone 1	2	......	j	......	Total
1	t_{11}	t_{12}		.		P_1
2	t_{21}	t_{22}		.		P_2
.				.		.
.				.		.
.				.		.
i				t_{ij}		P_i
.				.		.
.				.		.
.				.		.
Total	A_1	A_2	......	A_j	......	T



Pr/Att: Production and Attraction

Fig. 5-10 Process of Overcoming Practical Problem in Trip Generation Forecast

5.4.1 Growth Factor Method

A future trip distribution pattern can be derived by multiplying the existing pattern by a growth factor. The general form of this method is represented by the following equation.

$$T_{ij} = E \cdot t_{ij}$$

where,

T_{ij} = Future number of trips from zone i to zone j
t_{ij} = Existing number of trips from zone i to zone j
E = Growth factor

There are four types of growth factors: uniform factor, average factor, Detroit and Fratar methods.

Uniform Factor Method

The simplest method of forecasting future trip distribution. The growth factor is derived by consideration of the entire area under study which can be expressed as:

$$E = \frac{T}{t}$$

where,

E = Uniform growth factor
T = Total future number of trips in the study area
t = Total existing number of trips in the study area

Average Factor Method

This method has been developed to improve the Uniform Factor method to reflect the difference in growth rates in each of the zone pairs. This method divides growth rate values into different proportions in accordance with the individual growth in each traffic zone. The explanation is made through the equation given below

$$E = \frac{E_i + E_j}{2}$$

where,

$$E_i = \frac{G_i}{g_i} \quad \text{or} \quad \frac{A_i}{a_i}$$

$$E_j = \frac{G_j}{g_j} \quad \text{or} \quad \frac{A_j}{a_j}$$

and

E_i = Growth factor of zone i
E_j = Growth factor of zone j
a_i, a_j = Existing number of trip attraction of zone i, j
g_i, g_j = Existing number of trip generation of zone i, j
A_i, A_j = Future number of trip attraction of zone i, j
G_i, G_j = Future number of trip generation of zone i, j

Detroit Method

This method has been developed to solve the weak point in the uniform and average factor as well, and at the same time it lessens the cumbersome iteration process employed in the Fratar method. The Detroit method was developed during the Detroit Metropolitan Area traffic study in the United States. The calculation is similar to the Fratar method.

The equation appears as follows:

$$T = t_{ij} \cdot \frac{E_i \cdot E_j}{E}$$

where,

T_{ij} = Predicted future trips from zone i to zone j
t_{ij} = Existing number of trips from zone i to zone j
E_i, E_j = Growth factors for zone i and j
E = Growth factor for the area as a whole

Fratar Method[1]

This method is employed so as to solve the weak point encountered in the Uniform and the Average Factor Methods. The basic principle of this method is that:

- Future trip distribution is to be in direct proportion to the present trip distribution when origin of trip is taken into consideration.

- Future trip distribution can be derived from a multiplication of the growth factor of the zone to which these trips are attracted.

[1] Based on JICA (1984) 'Comprehensive Urban Transport Planning', PP IV 9-13

The steps of Fratar calculation are as follows:

1. Assuming that the trip ends (generation and attraction) are available, allocate the trip generation of a zone i to the rest of the zones in proportion to the present value of x_{ij}'s. Calculate, in the same manner, x_{ij}'s by using trip attraction of zone j. This yields two values for each inter-zonal movement (i -> j, j -> i), and the average of these two values is taken as the first approximation of the inter-zonal volumes.

2. For each zone, the sum of the initial approximation is divided into the total volume desired for the zone, as estimated from the trip generation stage, to derive the new growth factor to be used in computing the second approximation.

3. The estimated inter-zonal trips for each zone in the first approximation are again distributed, in proportion to the present interzonal volumes and the new growth factor obtained in the first approximation. The pairs of values derived are again averaged and the process repeated until conformity between calculated and 'desired' trips is achieved.

Mathematically, the Fratar method can be expressed as

$$T_{ij} = T'_{ij} \cdot F_i \cdot F_j \cdot \left(\frac{L_i + L_j}{2}\right)$$

$$F_i = \frac{T_i}{T_i} \qquad F_j = \frac{T_j}{T_j}$$

$$L_i = \frac{\sum_x T'_{ix}}{\sum_x (T'_{ix} \cdot F_i)} \quad , \quad L_j = \frac{\sum_x T'_{jx}}{\sum_x (T'_{jx} \cdot F_j)}$$

where, T_{ij} = Future trips from zone i to zone j

T'_{ij} = Present trips or trips calculated proceeding iteration from zone i to zone j

L_i, L_j = The reciprocal of the average attracting force of all other zones on zone i and zone j, and are often called the "Location" or "L" factor

T_i = Future trips generating and attracting in zone i

T_j = Present trips or trips calculated at proceeding iteration in zone i.

This process is repeated until F_i and F_j approximate the limiting value of 1.00.

5.4.2 Gravity Model

The gravity model has been inferred from Newton's law of gravity, in which two bodies in the universe attract each other in proportion to the product of their masses, and inversely to the square of their distance apart. The trip production and attraction are seen as the two masses and a measure of spatial distribution such as travel time and distance, is taken as the distance between the two 'masses'.

General Form

Gravity model has the general form of the equation shown below:

$$T_{ij} = P_i \frac{A_j D_{ij}}{\sum_{j=1}^{n}(A_j . D_{ij})}$$

when, T_{ij} = Trip having origin at zone i and destination at zone j

P_i = Trip production or generation of zone i

A_j = Trip attraction of zone j

D_{ij} = Friction factor

and $D_{ij} \propto d_{ij}$

or $D_{ij} = 1 / d_{ij}^{a}$

where D_{ij} = spatial separation between zone i and zone j generally expressed in travel time

assuming that $\Sigma (A_j . D_{ij}) = K$ (constant)

then $\frac{T_{ij}}{P_i A_j} = D_{ij}^{-a} . K^{-1}$; and

$$l_n\left[\frac{T_{ij}}{P_i A_j}\right] = -a l_n d_{ij} - l_n K$$

It can be seen that the above equation is in the form of linear regression. In order to examine the relation expressed in the above equation, the values are plotted as shown in Figure 5-11.

Example application of gravity model

One of the JICA studies applied the following model to estimate trip distribution.[1]

$$T_{ij} = P_i A_j \frac{K}{D_{ij}^{n\beta}}$$

where, T_{ij} = trip between zone i and j
P_i = trip produced by zone i
A_j = trip attracted by zone i
D_{ij} = travel time between zone i and j (min)
n, k = gravity model parameters

[1] JICA (1979) 'Comprehensive Study for Bangkok Sub-Urban Transport Project', Japan International Cooperation Agency

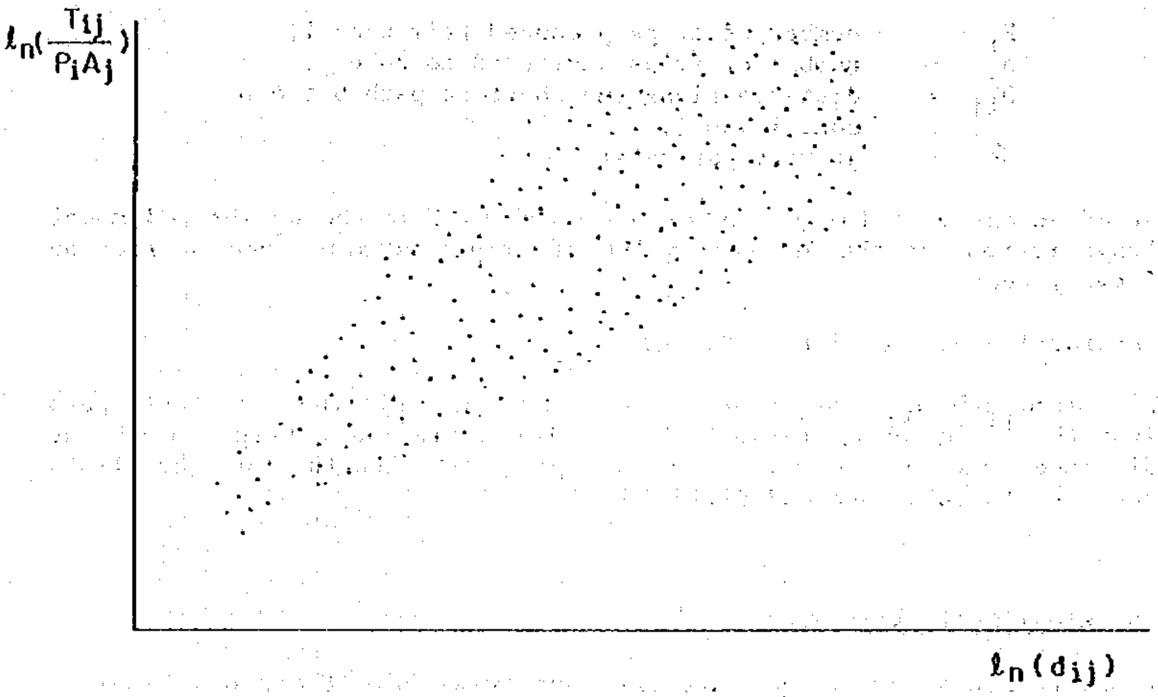


Fig. 5-11 Test of Gravity Relation

The calibration is performed for person trips and truck trips and the results are shown in Table 5-13.

Table 5-13 Example Gravity Parameters Used in a JICA Study

Trip Type	Gravity Parameters	
	K	n
Person Trips	0.158	1.329
Truck Trips	0.447	1.736

Fully Constrained Gravity Model

Trip distribution can also be estimated by a fully constrained gravity model:

$$T_{i} = A_i B_i p_i a_j D_{ij}^{-\beta}$$

where, T_{ij} = the number of trips between zone i and j

$$A_i = 1 / \sum_j B_j a_j D_{ij}^{-\beta}$$

$$B_j = 1 / \sum_i A_i p_i D_{ij}^{-\beta}$$

P_i = number of trips produced from zone i,
a_j = number of trips attracted to zone j,
D_{ij} = distance along the shortest path between zone i and j,
β = gravity parameter.

The advantage of a fully constrained model is that the calibrated model always reproduces the original value of trip generation and attraction of every zone.

Construction of Travel Time Matrix

The value of D_{ij} for $i = j$ is determined by the shortest path algorithm[1] by using network data. For intra-zonal trips, i.e. the 'distance' may be obtained by averaging the lengths of the links connected to that zone and divided by 2.

5.5 Modal Split Analysis

Transport modes such as private cars and buses have their own 'shares' in terms of total number of person trips that take place in a study area for a specified time period. The analysis of estimating the shares among different modes is called modal split analysis.

Long-term land use/transport planning concerns the planning for major transport networks, therefore, major transport modes such as private cars, buses and railway become the most relevant subjects of the analysis. The result of the analysis will be reflected in the planning for public transport systems as well as for highway network systems; the latter case sometimes requires the delineation of private and public transport users in the total person trips estimated for specific routes or areas.

Modal split analysis, however, is not used for cities where private transport plays the dominant role; in this case the planning gives emphasis to highway network systems, the demand analysis often adopts 'vehicular trip' as a analysis unit. The urban transport system, however, consists of a combination of various modes of transport and the maximum mobility and convenience can only be obtained by planning them as an integrated system made up of inter-related sub-systems. Therefore, even though, in the case where public transport planning does not take place simultaneously with the highway network planning, the mechanism of modal split should be well understood by the transport planner.

Factors Affecting Modal Split

A variety of methods have been developed to depict the modal mechanism; but most of them try to consider the merits (or demerits) of choosing one mode of transport over others. The merits of a transport mode are usually analyzed by the following three sets of factors:

[1] For further elaboration see Sec. 5.5

1. Characteristics of travel such as purpose, trip distance and the time of day the travel is made.

2. Characteristics of transport system such as travel time, cost, reliability and comfort.

3. Characteristics of travellers (trip makers) such as car-ownership and income.

Modal Split Approaches

The stages where modal split analysis is performed provide the most common method for classification of approaches. Three approaches are identified:

1. The approach which allocates trip ends (production and attraction) into different modes.

2. The approach which estimates number of trips between zone pairs for each mode and later compares them to obtain modal shares.

3. The approach which allocates inter-zonal trips into competing modes of transport.

The third approach known as 'trip-intercharge model' of modal split has been most practical in urban transport planning, which will be elaborated by explaining two most widely applied methods: diversion curve method and discrete choice modelling method.

Diversion Curve Method

Typical diversion curve method tabulates the proportion of person trip using particular transport mode and travel time ratio. Sendai Area Transportation Study, Japan[1] established diversion curves of public and private transport modes, and railway and buses as shown in Figure 5-12 and 5-13.

Discrete Choice Modelling

The application of this approach is based on economic consumer theory in that an individual chooses among alternatives so as to maximize his well-being. The theoretical background to this method and examples of using this model in modal split analysis are presented in PART 6 of this manual.

5.6 Traffic Assignment

Traffic assignment process is the process of estimating spatial distribution of traffic over transport network; the major input data are an O-D matrix and network data. There are various types of assignment method used in different purposes of analysis, but the occasions where this process takes place can be classified into two basic categories.

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[1] 'Sendai Area Transportation Study', Tohoku Region, Japan 1972-75

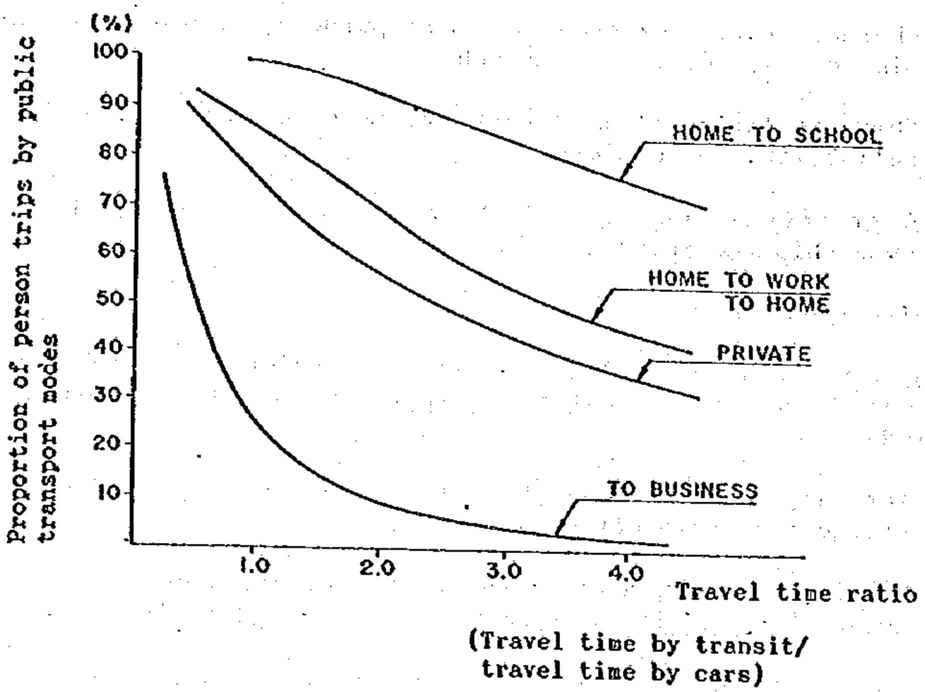

Fig. 5-12 Diversion Curves of Public and Private Transport Modes[1]

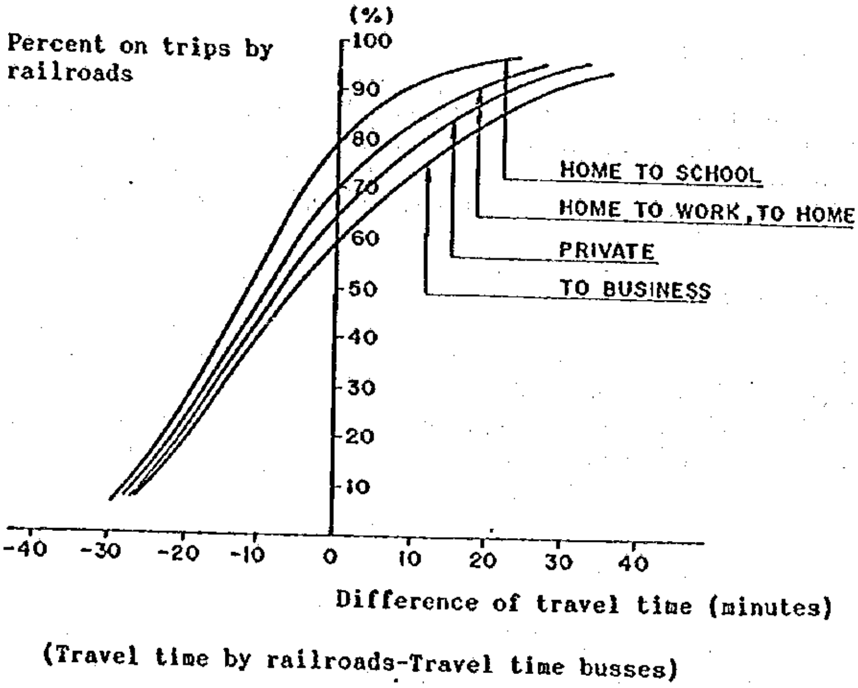

Fig. 5-13 Diversion Curves of Railroads and Buses[1]

[1] Ford, L.R., and D.R. Fulkerson. (1962), Flows in Networks, Princeton: Princeton University Press, PP 130-33.

1. The assignment of future trips to the existing road network to examine the deficiencies and to provide basic information for the network improvement planning.

2. The assignment of future trips to the future road network to evaluate the adequacy of the planned network, and to give additional information to further improvement of the plan.

5.6.1 Shortest Path Algorithm

The key algorithm to the assignment technique is the 'Shortest Path Algorithm' which finds out the shortest route (succession of assignment links) between two zones. For example, consider the diagrammatic network shown in Figure 5-14.

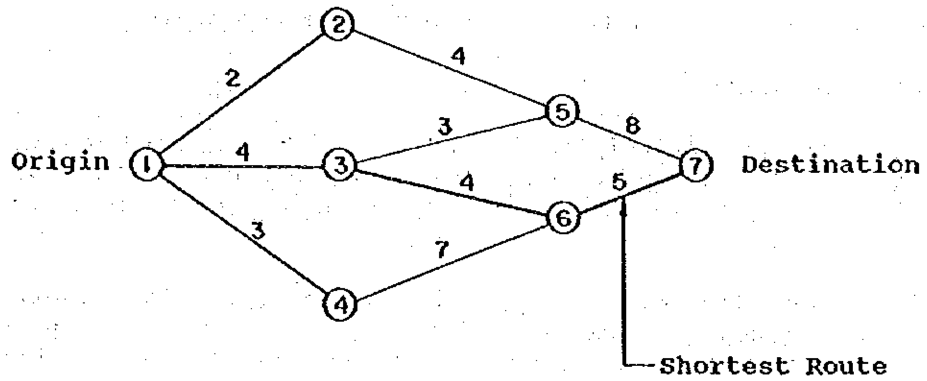

Figure 5-14 Diagrammatic Network Showing the Shortest Route

In the above Figure, the numbers along the link indicate the distance (Km) of link. Travel time (min) is also frequently used as the measure of travel cost.

In this example there are four routes from origin to destination : (1) 1-2-5-7, (2) 1-3-5-7, (3) 1-3-6-7, (4) 1-4-6-7. The distances along each route are: 14, 15, 13 and 16 Km respectively, and the shortest route is the third route which is 13 km long. The example shown here is rather simple but for the bigger scale network that may have more than 100 zones and 1000 links, an elaborate method such as Ford and Fulkerson's algorithm can be applied and solved by using a computer.

The Ford and Fulkerson's shortest path algorithm applies the concept of 'label'. A label consists of two elements and generally described as [i, p(j)]. The labels are attached from an origin node to all the destination nodes. Shortest-path trees and shortest distance matrix can be constructed from these labels.

Let l_{ij} be the link from node i to node j, and the cij the distance between these two nodes (the length of the link). The label [i, p(j)] is attached to node j, where p(j) indicates the sum of the distance from the origin node. The algorithm for labelling follows the steps:

1. Choose an origin node.

2. Denote this node with [-, 0].

3. Classify all the nodes into two categories: A and B; where, A is the set of labelled nodes and B is the unlabelled nodes.

4. Find all the links l_{ij} such that i belongs to A and j belongs to B; call this link set L.

5. Choose one link from the set L such that it minimizes $p(j) = p(i) + c_{ij}$; and denote this node with [i, p(j)].

6. Repeat 3-5 until all the destination nodes are labelled.

7. Back track to construct a shortest-path tree.

8. Repeat 1-7 until all the origin nodes are considered.

All or Nothing Assignment

One of the assignment principles known as 'all-or-nothing' assignment allocates <u>all</u> of the transport demand between two zones on the shortest route. The aggregation of the traffic using each link gives the estimated traffic volume.

Although it is unrealistic, this type of assignment is often applied to investigate the <u>potential</u> traffic volume. For a strategic planning purpose, this simple assignment is useful to examine the balance between cross-sectional traffic demand and the corresponding link capacities in the network.

Capacity Restraint Assignment

For the purpose of planning for more detailed network improvement, a realistic estimation of link volume is required. The number of vehicles that can pass a road section per specified time is limited, and the traffic build up the travel speed usually goes down leading to longer travel time than initially specified; the shortest path changes due to the increased travel time on congested links.

The capacity restraint approach considers this effect of congestion, which is simulated through the use of Q-V curves explained in Sec. 5.2.2.

<u>Incremental Loading</u> is the method used to assign O-D matrix on transport network, for example, 30, 30, 20, 10, 10% may be adopted and at each stage of loading the link speeds are calculated to renew shortest paths for all the zone pairs.
Certain computer code for traffic assignment adopt all-or-nothing assignment ingeniously to determine the loading ratio automatically within the computer. This method load 100% of O-D matrix first and determine V/C ratio of each link. Then, the highest V/C ratio is used to determine the first loading ratio, i.e. C/V. The Q-V curves are applied to renew the shortest paths and the 100% of the <u>remaining</u> O-D is again assigned to determine next loading ratio. The process continues until no more loading is possible. This method is particularly useful

for a peak hour traffic assignment in which the capacities of the links are treated as an upper limit of traffic assignment.

Capacity and traffic volume in the capacity restraint assignment is expressed in 'time interval': one hour (peak hour) or 24 hour (daily) traffic is usually adopted. The assignment by using peak-hour traffic and capacity is called 'peak-hour traffic assignment', the latter, is called 'daily traffic assignment'. Q/V relations are established by using time intervals that are shorter than one hour, therefore peak-hour assignment is theoretically more sound than daily traffic assignment, and this approach is regarded as the more accurate method. The peak-hour assignment, however, could often result in the situation where O-D trips cannot be fully loaded because of certain bottle necks in the assignment network. These left-over items cause some problems when different transport networks are to be compared by using the same O-D matrix. If the loading rates change depending on the transport network, the results could undermine the possibility of comparison.

In the daily traffic assignment technique, on the other hand, the Q/V relation is defined by a less rigorous concept and the 'capacity' of daily traffic is not the upper limit of traffic volume that can be accommodated on a link. The concept of capacity is used to represent the relative relation between traffic speed and traffic volume, and the network loading is usually performed until all the traffic in O-D matrix is loaded. The results obtained by daily traffic assignment is easier to interpret. There is no established criteria for the use of these two types of assignment approaches in different transport planning situations but, in general, the peak-hour assignment is used for short term traffic assessment, where peak-hour capacity is more critical; and the daily traffic assignment is used for medium to long term network planning.

Assignment of Public Transport Demand

The principles of the network assignment are directly applicable to the analysis of travellers movements on the public transport network. The network coding may require special attention to such arrangements as contra-flows and exclusive routes in a bus operation system, and pedestrian access links to and from bus stops or railway stations. Other factors such as time for transfer, waiting and walking are also taken into consideration.

Presentation of Results

The outputs from traffic assignment analysis may include:

- traffic volume;
- final speed (traffic speed at final loading);
- V/C ratios;
- trip length distribution; and
- O-D table using each link.

The assigned traffic volume can best be presented by a graphical format shown in Fig. 5-15. With this diagram, traffic concentration on each link can be overviewed. Similar graphics as well as tabulation can be made for final speed and V/C ratios. The characteristics of traffic on each link can best be judged from trip length distribution and O-D tables of each link. All of the above figures can be tabulated separatedly for modes (types of vehicle) or purposes depending on the resolution of the analysis required.

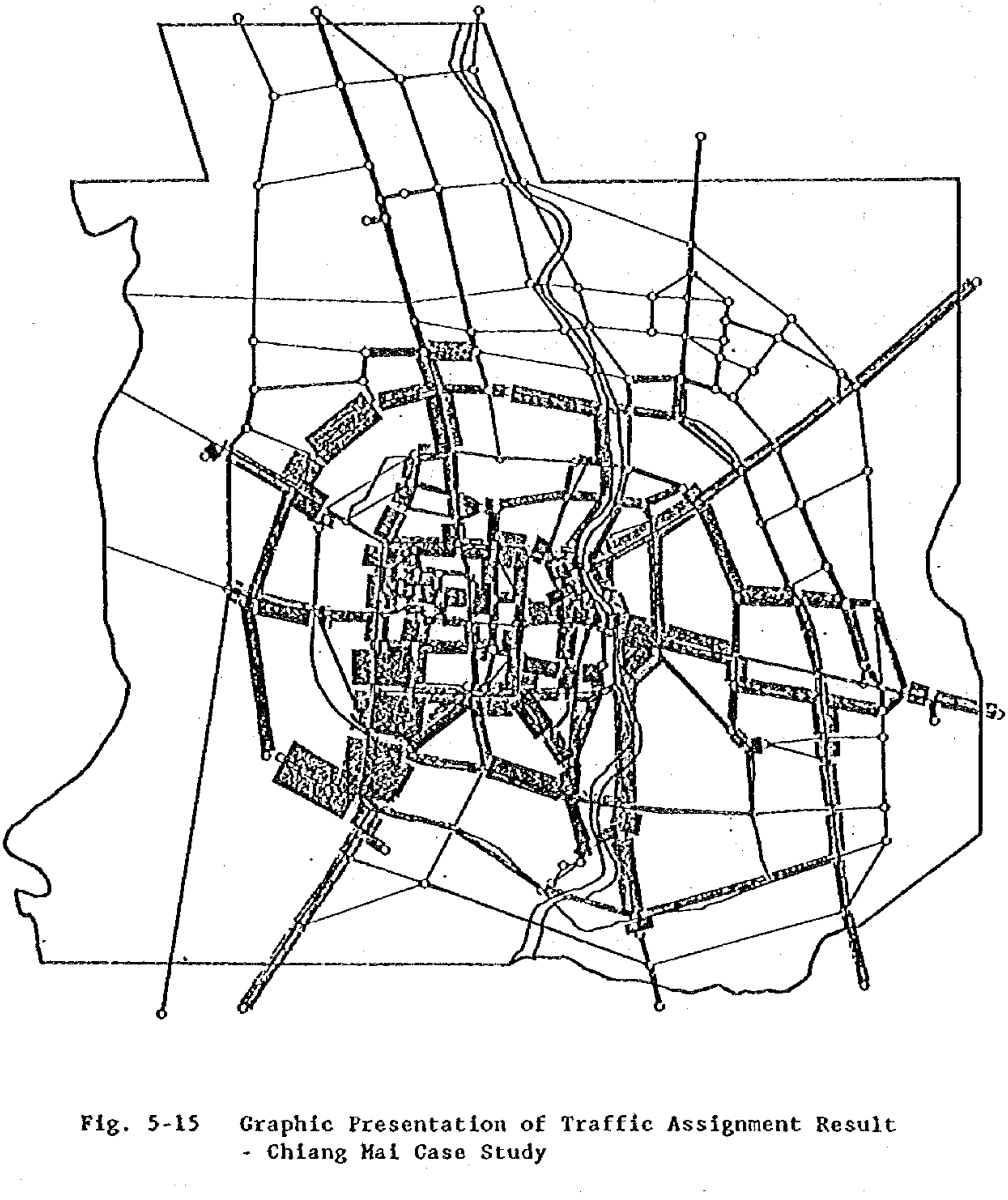

Fig. 5-15 Graphic Presentation of Traffic Assignment Result - Chiang Mai Case Study

PART 6:

Alternative Approaches to Demand Analysis

ALTERNATIVE APPROACHES TO DEMAND ANALYSIS

6.1 Introduction

In PART 5, the conventional modelling approach (four step model) to transport demand analysis was presented. The approach has firmly established the theoretical basis and a wide range of practical applications in many countries. The application of this approach to Thai cities has also been recommended, however, the full scale application requires a certain amount of resources which may not be justified in every case, particularly for medium to small cities.

The first of the sections following (Sec. 6.2) considers a simplified approach to demand analysis; and presents less data-demanding methods and the techniques to simplify the conventional modelling approach, of which a simplified approach to the estimation of O-D matrix is further elaborated in Section 6.3.

Section 6.4, on the other hand, introduces a somewhat different category of modelling known as 'discrete choice modelling' or a 'disaggregate modelling' approach to transport demand analysis. The understanding of this theory requires background knowledge on 'random utility theory'. Because of its potential for minimizing data requirements, especially in modal choice modelling as well as in route choice, and of its quality to reflect urban transport policies to planning process, the approach cannot simply be dismissed. Suggestions as to the area of possible application in Thai cities have been made in this section.

6.2 Simplified Approaches to Demand Analysis

Simplified methods of demand analysis can be classified into the following four categories:

1. Trend analysis
2. Road density approach
3. Simplified O-D data collection
4. Simplified modelling

The methods 1. and 2. are simple procedures suited for small cities with only a few trunk lines, but the accumulation of the past data especially for trend analysis - is required. Methods 3. and 4. are low-cost applications of the modelling method explained in PART 5, and may be suitable for small to medium cities.

Trend Analysis

Trend analysis applies the past trend to estimate future traffic demand. The concept is simple: find appropriate growth rate and multiply that to the present level of traffic. For example, a road section has ADT of 5000 veh/day, and the growth rate is 2% per year, the traffic volume in five years time is:

$5000 \times (1.02)^5 \longrightarrow 5520$ veh/day

The growth rate may be estimated from past traffic volume records or the increase rate of car-ownership of the area.

The assumption of this method is that the growth of the area remains steady, and no major land use development take place in the vicinity over the projected period. This assumption, however, may be valid only for remote cities for relatively short periods. As is shown in the Socio-Economic Research manual (Vol. III), there are other methods of projecting socio-economic indices for longer terms, and they should be applied if the trend analysis is to be applied to the preparation of general plan whose planning horizon is about 20 years.

Department of Highway (DOH) also issues standard growth rates based on past trends of traffic growth and future increases of car ownership. The growth rates are tabulated for every DOH road sections. (e.g. see Table 6-1) The relevant figures for planning can be utilized to estimate future traffic demand of surrounding links. The projected demand is compared with the existing capacities of highway sections and the improvements are specified to accommodate future demand.

Road Density Approach

The demand for urban road systems is dependent on the extent of urban development. The higher level of population usually indicates a higher level of development and requires more road space than smaller cities. If road density standards are available the requirement of urban road space is directly calculated. The concept and the example of road densities used in Japan are presented in PART 7.

Simplification in O-D Data Collection

It has been pointed out that one of the most time consuming parts of the modelling approach is the collection of O-D data. A few types of simplification can be made depending on the existing data availability.

When O-D surveys have been conducted for the concerned city in the past, the matrix may be updated by using Fratar method (see Section 5.4.1). Alternatively the trip estimation method from traffic counts can be applied, which will be explained in Section 6.3. When old data are not available for the concerned city, basic trip rate or parameters (such as in gravity model) calibrated for other cities with similar characteristics, may be used by assuming that these value remain constant over space (and time).

If no data is available and some sort of primary survey appears to be essential, an O-D survey can be conducted with a small sampling rate, alternatively, the survey can be conducted only for selected key traffic zones and the remaining zone pairs surveyed by mail reply method; in this method, questionnaires are distributed preferably through personal contact and left to be filled out by the respondents, and completed answers are returned by mail. Reliability of this method is lower than the interview method but the survey cost can be substantially reduced.

Table 6-1 Example of DOH Growth Rate Based on Historic Data

RT. NO.	CONT. SEC.	TERMINUSES	STATION (KM)	AOT. 1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	REGRESSION ANALYSIS GR. %	R^2	F-RATIO
	2	MAE CHAN - MAE SAI	872+160	278	179	815	616	1756	2460	2422	1905	3285	3500	36.93	0.82	37.6
	2	MAE CHAN - MAE SAI	860+042	330	116	383	685	1181	1775	2275	1997	2153	2381	35.80	0.79	30.8
111	1	SAKLEK - PHICHIT	3+000	0	0	1000	838	1052	1396	1380	1508	1713	1469	9.13	0.76	19.1
113	1	MANGCOMPHU - CHONDAEN	64+000	0	0	0	0	799	727	792	930	875	789	1.88	0.16	0.8
	1	YAK KHAOSAI - MANG THONG THAI DONG	2+000	0	0	58	0	0	0	0	0	0	0			
	2	CHONDAEN - KHAO SAI	42+000	481	971	925	1043	1143	1271	1752	1456	1525	1286	10.14	0.65	15.2
	3	KHAOSAI - TAPHANHIN	10+000	1589	1729	1956	2047	2154	2296	2767	2705	2834	2460	6.24	0.85	44.1
114	1	ROUTE NO.11 (KM. 5+700) LAMPHUN	2+500	0	0	0	1275	881	1010	1504	1512	1795	2362	14.03	0.71	12.5
115	201	KAMPHAENGPHET - SAM NGAM	2+000	0	0	0	0	528	753	2477	1876	2193	1911	30.66	0.61	8.3
	3	SAM NGAM - PHICHIT	86+804	0	0	243	496	627	717	834	1070	1276	978	21.31	0.81	25.7
2	1	SARABURI - MUAK LEK	129+000	4654	4774	5496	5700	5821	6156	6489	7064	7414	4893	3.22	0.35	4.4
	302	MUAK LEK - SIKHIU (C)	189+100	4807	3970	4497	4280	4573	5159	5570	5372	5854	5525	3.58	0.66	17.2
	402	SIKHIU - NAKHONRATCHASIMA	223+300	5335	5539	5555	5403	5372	5834	5948	6004	6028	5953	1.43	0.74	22.7
	502	NAKHONRATCHASIMA - PHIMAI	0+500	5940	5883	9086	7258	7968	6367	5638	5203	5417	5352	-3.15	0.27	2.9
2	502	NAKHONRATCHASIMA - PHIMAI	6+300	4208	4633	3854	3939	3987	3744	3638	4553	4611	3502	-0.70	0.04	0.4
	502	NAKHONRATCHASIMA - PHIMAI	15+000	0	0	0	0	0	0	5135	0	0	0			
	502	NAKHONRATCHASIMA - PHIMAI	24+295	0	1564	1466	2665	2789	3094	3272	3413	3412	3676	11.64	0.78	24.9
	6	PHIMAI - BAN NAT (C)	47+450	2608	2823	2870	2501	2651	3077	3318	3596	4059	4003	5.30	0.79	29.4
	6	PHIMAI - BAN SIDA (C)	49+200	0	0	0	0	0	0	3102	0	4059	0			
	6	PHIMAI - BAN SIDA	58+230	1173	1262	1601	1110	1243	1972	1882	2084	2112	2229	8.03	0.73	21.4
	6	BAN WAT - BAN SIDA	473+022	1203	1303	1408	1148	1115	2913	3237	1600	3577	1830	10.28	0.44	6.2
	702	BAN SIDA - PHON (C)	365+548	2831	2955	3360	2480	2807	3190	3517	3601	3271	3189	2.02	0.28	3.1
	702	BAN SIDA - PHON	493+000	0	0	0	0	0	0	0	3125	0	0			

(Source: Department of Highways)

For smaller cities (say less than 5,000 population), main traffic movement can be worked out by a cordon O-D survey only. This method is more reliable compared to a number,plate survey and gives more detailed information on the origin and destination, purpose, mode of travell and travellers characteristics. Medium cities (e.g. up to 75,000 population) could apply dual cordon O-D survey in which an external cordon is set at the fringe of city and an internal cordon is set to encircle the city centre. This will lead to substantial resource savings compared to a full-scale O-D survey while providing vital but sufficient information concerning traffic movement in this scale of city.

Use of residence-workplace information, collected as part of socio-economic survey, to simulate morning peak traffic movement, is another approach that has to be investigated in detail to avoid a costly O-D survey.

Simplified Modelling

Demand analysis may be simplified by the following three methods:

- Restriction of parameters and zone number.
- Use of simpler models in the four step demand analysis.
- Use of modelling techniques which require less data.

Restriction of parameters. may be achieved through, for example aggregation of trip purposes, or use of smaller number of transport models; vehicular trips only may be sufficient for relatively smaller cities.

Aggregation of traffic zones. is another method of simplification. Kurokawa and Asano (1981) found that the aggregation of traffic zones do not affect the assignment result substantially, particularly when the capacity restraint assignment is employed.

Use of simple models. in the process of traffic generation, distribution and assignment can reduce the cost of analysis in data preparation, computing etc. Trip rate method by using population of unit land use is simple to apply compared with, for example, regression models in trip generation estimate.

Present pattern method. such as Fratar method is sufficient for slow growth area in trip distribution. All or nothing assignment may be most appropriate for cities with simple network structure.

Discrete choice modelling. (see Section 6.4) uses less data compared with the four step demand analysis approach. Disaggregate approach uses individual choice data, bases its theory on consumer behaviour theories. Most popular application of this technique is to modal split analysis, but it can be applied to any other transport choice situation so as to replace the four step approach. While some transport planners are critical about the value of this technique in the demand forecasting process, the number of successful applications is growing[1].

[1] Ben-Akiba, M., and Lerman, S.R. (1985), Discrete Choice Analysis: Theory and Application to Travel Demand; Cambridge : MIT Press.

6.3 Estimation of O.D. Matrix Based on Traffic Counts

In the foregoing sections it has been pointed out that O.D. matrix is essential for the four step demand forecasting method. In order to construct O.D. matrix, a home interview survey has to be conducted but this kind of survey, and the construction of O.D. matrix from the collected data, are very time consuming. The validation of the resultant matrix is usually made by assigning it on to existing traffic network and by comparing the results with actual traffic counts. Taking this point into consideration, there has been a growing concern over the method of estimating O.D. matrix from traffic counts. Major benefit of such a method is that the full scale home interview survey may be substituted by a less costly survey of traffic counts, which usually can be performed by automatic traffic counters.

Willumsen reviewed the models put forward for this purpose[1]. Some of the general characteristics of these models are discussed in this section and the procedures for practical application are explained.

Consider a study area with M traffic zones; then, there will be M^2 unknown to form an O.D. matrix, which have to be estimated through observed link flows. For making the problem tractable, it is convenient to introduce the variable which is defined as the proportion of traffic on link a which has origin zone i and destination j.

In general, the values of P_{ij}^{a} lie between 0 and 1, i.e.

$$0 \leq P_{ij} \leq 1$$

$P_{ij}^{a} = 0$ if no trips between i and j use link a, and $P_{ij}^{a} = 1$ if all the trips use link a.

If we denote the flow on link a by V_a, the basic equation in the estimation of a trip matrix from the link volume is :

$$V_a = \sum_{i}\sum_{j} P_{ij}^{a} \, T_{ij} \qquad \ldots\ldots\ldots \quad (1)$$

where, T_{ij} is the total number of trips from zone i to zone j .

The values of P_{ij}^{a} can most appropriately be assumed to be dependent on traffic volume, but the congestion effects cause some complications which have not been solved satisfactorily. More tractable approach is to assume that the P_{ij}^{a} is independent of the flow level of each link, then, the value of P_{ij}^{a} can be determined independently of the estimation of the trip matrix. This latter approach is equivalent to assuming 'proportional assignment' in which the proportion of drivers choosing each link is assumed to depend on driver and route characteristics only; typical of such method is, for example, all or nothing assignment.

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[1] Willumsen (1981) Estimation of An O-D Matrix from Traffic Counts : A Review, Institute for Transport Studies Working Paper 99, Leeds University.

The problem of estimating the trip matrix is to find the value of T_{ij} from as many equations as the number of links with observed link flow. The number of unknowns exceeds the number of equations in most of the problems and the problem becomes underspecified. The number of unknowns may be reduced by making some assumptions about trip making behaviour, and there are three types of approaches.

Approaches based on gravity model

Many of the approaches assume that the trip making behaviour is reasonably represented by a gravity model. By doing this, the number of unknowns is radically reduced. Robillard suggested the incorporation of a generalized gravity model[1]:

$$T_{ij} = R_i S_j f(C_{ij}) \qquad \text{.......... (2)}$$

R_i's and S_j's are the parameters to be calibrated, and where $f(C_{ij})$ is a deterrence function of the cost of traveling between i and j. More conventional gravity models have also been incorporated and approached by maximum likelihood method to calibrate the parameters. These models have been criticized for not making full use of the information contained in the observed traffic counts and forcing the trip matrix to follow a gravity type pattern[2]. This is critical in small or inner city areas where most of the trips have their origin or destination (or both) outside the area.

An alternative approach is to search for the O.D. matrix which is consistent with the information contained in the traffic counts, with minimum external information. Willumsen employed entropy maximizing approach[3] and formulated the above problem as follows:

$$\text{Max } S = -\sum_{ij} (T_{ij} \log T_{ij} - T_{ij}) \qquad \text{........ (3)}$$

$$\text{Subject to } V_a - \sum_{ij} T_{ij} P_{ij}^a = 0 \text{ and } T_{ij} \geq 0 \qquad \text{........ (4)}$$

for all counted links a. by forming the Lagrangean and differentiating it, T_{ij} can be obtained as follows :

$$T_{ij} = \exp\left(-\sum_a \lambda_a P_{ij}^a\right) \qquad \text{......... (5)}$$

where, λa is Lagrargean multiplier associated with the constraints on link a. By replacing $e^{-\lambda a} = X_a$, we obtain

$$T_{ij} = \prod_a X_a^{P_{ij}^a} \qquad \text{......... (6)}$$

[1] Robillard P. (1975) Estimating an O-D Matrix from Observed Link Volumes, Transport Research 9, 123-128.

[2] Van Zuylen, H.J., and Willumsen, L.G. (1980), The Most Likely Trip Matrix Estimated from Traffic Counts, Transportation Research B, Vol. 14B, pp 281-293.

[3] Willumsen (1978) Estimation of An O-D Matrix from Traffic Counts: A Review, Institute for Transport Studies Working Paper 99, Leeds University.

The extension to this model can be made to incorporate prior information such as old O.D. matrix and result is obtained as :

$$T_{ij} = t_{ij} \prod X_a P_{ij}^a \qquad \text{.........(7)}$$

where,

$$X_a = (\Sigma t_{ij})^{1/L} e^{-\lambda a}$$

and L is the number of counted links.

The following matrix may be used as prior information :

1. an old trip matrix;
2. a trip matrix obtained from a small sample survey, probably roadside interviews; and
3. a trip matrix synthesised with gravity type models.

In the case where no information is available to produce a prior matrix, an assumption that $f_{ij} = 1$ for all ij, $(i \neq j)$ may reasonably be made.

Solution Method

The equation (7) is called multi-proportional problem and the solution procedure is outlined below, based on Van Zuylen and Willumsen[1].

The algorithm involves an iterative modification of trip matrix until the calculated link flows are made equal to the observed ones.

(i) Calculate the values of P_{ij}^a by applying suitable assignment method and set the number of iterations n = 0

(ii) Set $X_a^n = 1$ for all links.

(iii) Set a = 0

(iv) Set a = a+1, and calculate the flow V_a^n.

$$V_a = \Sigma_{ij} t_{ij} \left(\prod X_a n P_{ij}^a\right) P_{ij}^a$$

and make $X_a^{n-1} = X_a^n . Y_a P_{ij}^a$

where Y_a is to be obtained by solving

$$V_a = \Sigma_{ij} P_{ij}^a \cdot t_{ij} \left(\prod X_a n P_{ij}^a\right) Y_a P_{ij}^a$$

(v) Go back to (iv) if $(a \leq L)$, where L is the number of links. Otherwise check for convergence condition set in step (vi).

(vi) Stop if $|V_a^{n-1} - V_a^n| \leq \varepsilon$ for all a where ε is sufficiently small number. If this condition is not met increment n by i and proceed to step (iii).

6.4 Discrete Choice Modelling

Discrete choice modelling in transport demand analysis is a rather new approach compared with the four step approach described in PART 5. The discrete choice approach is based on economic consumer theory in that an individual chooses among alternatives so as to maximize his well-being. There are a number of approaches in discrete choice modelling depending on how the decision problems are defined and subsequent analytical and computational treatments carried out, but some of the most widely used methods will be explained here.

Discrete choice models are sometimes called 'disaggregate models'. The usual travel demand analysis proceeds with the subdivision of the geographical area into 'traffic zones', and a zone centroid represents the origins and destinations of all travellers leaving or arriving that zone. This approach is sometimes called aggregate modelling because it utilizes the data on travel behaviour by aggregating observational units within a geographical zone and apply statistical analysis on these aggregate data.

The four step method explained in the previous sections is seen in the category of aggregate approach. Although this approach is well established in terms of its wide acceptance in practical applications, its shortcomings are also widely discussed (e.g. Spear, 1979; JICE, 1984) which can be summarized as follows:

1. Person trip based survey for aggregate demand analysis is costly to attain sufficient statistical reliability.

2. Zonal aggregation of data sometimes makes it difficult to establish clear theory of decision problems such as modal split analysis.

3. Because of the aggregation, some useful information might be lost.

4. Aggregate models are not suitable for policy analysis.

Discrete choice models, on the other hand, have favourable properties that can counter the above criticisms. In the following sections, the basic theory' modelling procedure and example applications to transport demand analysis will be explained.

Random Utility Theory and Discrete Choice Models

Consider the situation where an individual n faces the problem of choosing alternative i or j. This is a binary choice situation. If he prefers alternative i over j, then the utility of choosing i is bigger than the utility of choosing j, i.e.

$$U_{in} > U_{jn}$$

The forms of the utility, however, are not known to the analyst with certainty; therefore are best treated as random variables. The probability of this individual choosing P_{in} can be expressed as follows:

$$P_{in} = P_r (U_{in} > U_{jn})$$

Utilities can be divided into two additive parts as follows:

$$U_{in} = V_{in} + \varepsilon_{in}$$

$$U_{jn} = V_{jn} + \varepsilon_{jn}$$

where, V_{in} and V_{jn} are called the 'systematic' components of utility i and j; ε_{in} and ε_{jn} are called the random components.

V_{in} and V_{jn} are usually linear additive functions and are assumed to be deterministic. ε_{in} and ε_{jn} may also be functions, but they are random variables from the analyst's point of view.

Therefore, the probability of the individual choosing i can be rewritten as follows:

$$\begin{aligned} P_{in} &= P_r (U_{in} > U_{jn}) \\ &= P_r (V_{in} + \varepsilon_{in} > V_{jn} + \varepsilon_{jn}) \\ &= P_r (\varepsilon_{ij} - \varepsilon_{in} < V_{in} - V_{jn}) \end{aligned}$$

then, the form of P_{in} depends on the assumption made to the distribution of ε's .

Probit Model

One logical assumption is to view that ε's are 'normally distributed' with zero means and variance σ_i^2 and σ_j^2 , respectively, and have covariance σ_{ij} . Then

$$P_{in} = \int_{-\infty}^{(V_{in} - V_{jn})/\sigma} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}u^2} du$$

where, $\sigma^2 = \sigma_i^2 + \sigma_j^2 - 2\sigma_{ij}$

For convenience we make an arbitrary assumption that $\sigma = 1$.

This model is called 'binary probit model'. The choice probability of this model, however, can not be expressed in a closed form, and has to be expressed as an integral, which leads to the searching for more analytically tractable model while maintaining properties similar to the binary probit model.

Logit Model

One such model is binary logit model in which 's are assumed to be logistically distributed, or ε_{in} and ε_{jn} are independently and identically 'Gumbel' distributed, i.e.

$$F(\varepsilon) = \frac{1}{1+e^{-u\varepsilon}} \qquad u > 0, -\infty < \varepsilon < \infty$$

$$f(\varepsilon) = \frac{ue^{-u\varepsilon}}{(1+e^{-u\varepsilon})^2}$$

where u is a positive scaler.

Under the above assumption, the choice probability for alternative i is given by

$$P_{in} = P_r \{ U_{in} > U_{jn} \}$$

$$= \frac{1}{1+e^{-u(V_{in}-V_{jn})}}$$

$$= \frac{e^{uV_{in}}}{e^{uV_{in}} + e^{uV_{jn}}}$$

In general, u is assumed to be 1.

The case for multinomial choice, the above equation can be extended to 'multinomial logit' (MNL) model which is expressed as:

$$P_{in} = \frac{e^{V_{in}}}{e^{V_{in}} + e^{V_{jn}} + , \cdots\cdots, + \cdots\cdots}$$

$$= \frac{e^{V_{in}}}{\Sigma_{j \varepsilon C_n} e^{V_{jn}}}$$

where C_n is the choice set available to individual n .

Parameter Estimation

The widely applied technique to estimate model parameters is called 'maximum likelihood estimation method'. Least square method can also be applied, but it is computationally difficult and has no advantage over maximum likelihood method.

Maximum likelihood method is the approach to estimate the value of parameters for which the observed sample is most likely to have occurred. Likelihood function in binary choice model is expressed as below.

$$\mathcal{L}^* (\beta_1, \beta_2, \ldots\ldots \beta_k) = \prod_{n-1}^{N} P_{in}{}^{Y_{in}} P_{jn}{}^{Y_{jn}}$$

where, $\mathcal{L}^*$ = Likelihood function

β = ^{k}th parameter

N = Number of samples

Y_{in} = { 1 if person n chooses alternative i, 0 if person n chooses alternative j.

By taking natural logarithm, the above equation is transformed as follows:

$$\mathcal{L}(\beta_1,\ldots\ldots,\beta_k) = \sum_{n-1}^{N} [y_{in} \log P_{in} + y_{in} \log P_{in}]$$

$$= \sum_{n-1}^{N} \left\{ y_{in} \log P_{in} + (1-y_{in}) \log [1-P_{in}] \right\}$$

$$(\because y_{jn} = 1 - y_{in} \text{ and } P_{jn} = 1 - P_{in}$$

maximum of $\mathcal{L}$ can be obtained by differentiating the function by and β 's and equating it to zero, and solving the resulting set of equations for β's

The differentiation of the above equation becomes:

$$\frac{\partial \mathcal{L}}{\partial \beta k} = \sum_{n-1}^{N} \left\{ Y_{in} \frac{\partial P_{in} / \partial \hat{\beta}_k}{P_{in}} + Y_{jn} \frac{\partial P_{in} / \partial \hat{\beta}_k}{P_{jn}} \right\} = 0$$

In the case of logit model, $\mathcal{L}$ is globally concave and the second order derivatives can be computed without great difficulty, the above set of equations can be solved by applying 'Newton Raphson method'. For estimation of probit model - particularly multinomial probit - is more complicated, but interested readers may refer to Daganzo (1979).

Modelling Procedure

Modelling procedure of discrete choice analysis is summarized as follows:

1. Model System Design: Determine model structure, alternatives, and the possible forms of utility functions.

2. Data Collection: Sample design, questionnaire design data collection (home interview etc.), coding and validation.

3. Basic Analysis: By using the collected data, basic statistics are tabulated (e.g. number of valid samples, socio-economic characteristics of respondents etc.). Major determinants to the choice of alternatives may be investigated by using statistical techniques such as 'Discriminant Analysis'. At the end of basic analysis, data file containing relevant variables, which is compatible with model estimation program may be created.

4. Model Estimation: Maximum likelihood estimation is most widely used technique to estimate parameters from observed data. Ready made software is available for this purpose.

5. Statistical Tests: Examine statistical properties for the evaluation of the model. Most of the important tests are included in the standard software along with their interpretations. Return to Step 4. if the model is not adequate.

6. Check Predictive Accuracy: Design for aggregation method and test of the estimated model by using data set that was not used to estimate the model. Return to step 4. if necessary.

7. Forecasting and Policy Analysis: Use the estimated model for forecasting and policy analysis.

Applications to Transport Demand Analysis

Discrete choice models can be used in a variety of situation in transport demand analyses. Typical areas of application are listed below:

- Residential Location;
- Workplace Choice;
- Automobile Ownership;
- Destination Choice;
- Mode Choice; and
- Route Choice.

Example model (binary logit model) calibrated for mode choice is shown as follows (Cambridge Systematics, 1976):

$$P(transit) = \frac{e^{V(transit)}}{e^{V(transit)} + e^{V(auto)}}$$

$$\text{where, } V(Auto) = 1.454 - 0.00897X_2 = 0.0308X_3 - 0.0115X_4 + 0.770X_6 - 0.561X_7$$

$$V(Transit) = - 0.00897X_2 - 0.0308X_3 - 0.00708X_5$$

and,

X_2	In-Vehicle time (min)
X_3	Out-of-Vehicle time (min)
X_4	Auto out of pocket cost (Cent)
X_5	Transit fare (Cent)
X_6	Auto ownership (auto specific)
X_7	Downtown Workplace Dummy (auto specific)

Questionnaire Design

The purpose of the data collection for discrete choice modelling is to investigate the behavioural pattern of travellers concerning travel decision-making, i.e. a choice situation. The questionnaire must cover three basic categories of information:

1. travellers' attributes;
2. alternative choice set; and
3. attributes of alternatives.

Travellers' attributes. Utility of choosing an alternative depends on the traveller's value system which can be reflected on the models through travellers' attributes such as income, age, car-ownership and occupation. In discrete choice analysis, when applied to modal split, availability of transport mode is particularly important to determine possible range of choice space. Car-ownership as well as drivers' licence, bus & railway availability to the respondents should be surveyed.

Alternative choice set. Each traveller could have different set of alternatives. If there is no bus service near his house, then, it is impossible for him to go to somewhere by bus. Other people may be limited from private car for not having either drivers' licence or motor vehicle; for these people their choice set is limited and this limitation changes from one person to another. The discrete choice modelling can handle this situation and every item of data can be utilized in the modelling process. The question regarding the choice set provides one of the most important items of information in discrete choice modelling.

Attributes of alternatives. Each alternative has its own attributes, for example, in-vehicle time, waiting time and fares for buses and trains, and door-to-door travel time and cost of gasoline for private cars. Reliability and comfort is other important element but these attributes have to be expressed quantitatively by using some kind of surrogate measures. The major difference of the interview survey for discrete choice modelling from conventional person trip O-D survey is that the respondents are asked about the attributes of alternatives that are not actually chosen. In certain cases additional field survey or other type of data collection are required to supplement these data, by using such as bus route map and operation schedule.

An example interview sheet for the discrete choice modelling as it is applied to modal choice analysis is shown in Figure 6-1.

Sample Design

Sampling principle for discrete choice analysis is basically the same for O-D surveys. The statistically reliable sample size cannot be directly calculated for the discrete choice modelling, but experience suggests that 300~1000 is sufficient for most cases[1].

A unique characteristic of sampling method for discrete choice modelling is that equal number of sample can be chosen from each alternative - which is called 'choice based sampling' - and the sampling rate of each alternative can be reflected in the modelling process.

[1] JICE (1984) Disaggregate Demand Modelling : Theory and Practice (in Japanese), JICE Seminar No. 15, Japan Institute of Civil Engineers, Tokyo:Dobokugakkai

Fig. 6-1 Example of Questionnaire for Discrete Choice Modelling Applied to Modal Choice

Part 1 Interviewed Data (for official use only)

1. Data No. 1 ☐☐☐☐
2. Date of Interview..............................
3. Place of Interview..............................

Part 2 Personal Data

1. Age ○ 1. less than 20 ○ 2. 20~29 ○ 3. 30~39 ○ 4. 40~49 ○ 5. 50~59 ○ 6. over 60 — 2 ☐
2. Sex ○ 1. Male ○ 2. Female — 3 ☐
3. Occupation — 4 ☐
   - ○ 1. Vocational skilled worker or technologist
   - ○ 2. Executive and management administrator
   - ○ 3. Clerical worker
   - ○ 4. Business traders
   - ○ 5. Agriculture, livestock, forestry, fishery
   - ○ 6. Mineral-mining, rock-crushing or well-drilling
   - ○ 7. Driver and attendant
   - ○ 8. Foreman or production-processor and labourer
   - ○ 9. Service worker
   - ○ 10. Student
   - ○ 11. Housewife
   - ○ 12. Unemployed
   - ○ 13. Retired
   - ○ 14. Others
4. Household Status ○ 1. Household ○ 2. Member — 5 ☐
5. Household Income — 6 ☐
   - ○ 1. Below 2,000 Baht/month
   - ○ 2. 2,000~3,999
   - ○ 3. 3,000~4,999
   - ○ 4. 5,000~8,999
   - ○ 5. 9,000~14,999
   - ○ 6. Over 15,000
6. Number of Family Members _ _ _ _ _ persons — 7 ☐
7. Drivers' Licence (Automobile) ○ 1. have ○ 2. not have — 8 ☐
8. Drivers' Licence (Motor Cycle) ○ 1. have ○ 2. not have — 9 ☐
9. Car Ownership ○ 1. not have ○ 2. one ○ 3. two ○ 4. three or more than — 10 ☐
10. Motor-Cycle ○ 1. not have ○ 2. one ○ 3. two ○ 4. three or more than — 11 ☐
11. Bicycle ○ 1. not have ○ 2. one ○ 3. two ○ 4. three or more than — 12 ☐

Part 3 Data on Trip Characteristics

1. Most Frequent Trip is ○ 1. to work ○ 2. to school ○ 3. to shopping ○ 4. private business — 13 ☐
2. Please answer the following questions about your most frequent trip (Origin and Destination)
   - 2.1 Original Place to Start a Trip — 14 ☐
     - Name of Place:..............................
     - No.:..............................
     - Alley/Lane:..............................
     - Road/Canal:..............................
     - Tambon:..............................
     - Amphoe:..............................
   - 2.2 Destination of Trip — 15 ☐
     - Name of Place:..............................
     - No.:..............................
     - Alley/Lane:..............................
     - Road/Canal:..............................
     - Tambon:..............................
     - Amphoe:..............................
3. Distance from origin to destination is approximately km — 16 ☐

Part 4 Mode of Travel

1. Can you go by Bus ? ○ 1. Yes ○ 2. No — 17 ☐
   - In-vehicle time _ _ _ _ _ _ minutes — 18 ☐
   - Access time (walking or bicycle) _ _ _ _ minutes — 19 ☐
   - Waiting time (total) _ _ _ _ _ _ minutes — 20 ☐
   - Total travel time _ _ _ _ _ _ minutes — 21 ☐
   - Fare (one-way) _ _ _ _ _ _ Baht — 22 ☐
   - Number of transfers (change of buses) _ _ _ times — 23 ☐
2. Can you go by Car ? ○ 1. Yes ○ 2. No — 24 ☐
   - Total travel time _ _ _ _ _ _ minutes — 25 ☐
   - Cost of gasoline (one-way) _ _ _ _ _ Baht — 26 ☐
   - Access time from parking _ _ _ _ _ minutes — 27 ☐
   - Number of passengers (include driver) _ _ _ persons — 28 ☐
3. Can you go by Motor-Cycle ? ○ 1. Yes ○ 2. No — 29 ☐
   - Total travel time _ _ _ _ _ _ minutes — 30 ☐
   - Cost of gasoline (one-way) _ _ _ _ _ Baht — 31 ☐
4. Can you go by Bicycle ? ○ 1. Yes ○ 2. No — 32 ☐
   - Total travel time _ _ _ _ _ _ minutes — 33 ☐
5. Can you go on Foot ? ○ 1. Yes ○ 2. No — 34 ☐
   - Total travel time _ _ _ _ _ _ minutes — 35 ☐

Part 5 Mode Choice

1. Frequency of Vehicle Type being Used for the above Topic

Category of Vehicle						
1. Bus	○1	○2	○3 —	○4	○5	36 ☐ 37 ☐
2. Car	○1	○2	○3 —	○4	○5	38 ☐ 39 ☐
3. Motor-Cycle	○1	○2	○3 —	○4	○5	40 ☐ 41 ☐
4. Bicycle	○1	○2	○3 —	○4	○5	42 ☐ 43 ☐
5. Walk	○1	○2	○3 —	○4	○5	44 ☐ 45 ☐

1. Every Day
2. Occasionally
3. Never Used
4. Inconvenient
5. Impossible

2. Reasons for not Using Private Car (multiple answer)
   - ○ 1. Take too much time — 46 ☐
   - ○ 2. Too expensive to run — 47 ☐
   - ○ 3. Unreliable (too much variation in travel time) — 48 ☐
   - ○ 4. No driver's licence — 49 ☐
   - ○ 5. Car is used by other member of family — 50 ☐
   - ○ 6. Car is not available — 51 ☐

This data information will be treated by as confidential and shall be strictly for an official use by the Town-Planning Office.

- Thank You -

(For Official Use Only)

○ Data coding is not completed
○ Examined is OK

PART 7:

Plan Synthesis – Guidelines to Better Plan Designing

PLAN SYNTHESIS - GUIDELINES TO BETTER PLAN DESIGNING

7.1 Introduction

The plan design stage is usually conducted by trial and error process in which a rough draft plan is successively improved by qualitative and quantitative assessment in cooperation with land use planners. The result of the assessment will be fed back into next trial until no further improvement can be made. Plan design is an act of synthesis in which the planner tries to find solutions of predefined planning problems by giving practical interpretations to all the information collected.

When more than one scenario (set of policies and assumptions) can be identified, due to uncertainty elements involved in planning, alternative (draft) plans may be prepared according to each set of scenario. Single draft plan may be sufficient for a small city where the rate of urban development is modest and no drastically different future developments can be assumed.

The collected information and the result of analyses are summarized here again to be used in the plan design process; the list of information that should re-assembled is shown below:

- Topographic map
- Existing land use
- Existing traffic volume
- Existing cross-section diagrams
- Right of way
- Future land use
- Future proposal of transport system by related authorities
- Future transport demand pattern
- Socio-economic data (Existing and Future)

Plan design process specifies 'planning elements' so as to meet a set of design requirements. Elements of transport plan in the general plan are the network of right-of-way for transport systems particularly highway network and pedestrian footpath, location of land for transport terminals. The design requirements consists of transport development framework, constraints and targets. These concepts are elaborated in the following sections.

Elements of Transport Plan

Major component of a transport plan in a general plan is the specification of right of way (e.g. Table 7-1,7-2) for the vehicular transport network to provide physical communication channel between land use activities. The specification of right of way depends on the expected volume of traffic,existing right of way and the type of frontage land use, In some cases, extra space is required for urban utilities. The guidelines are available for the specification of physical dimensions of roadways, but the land use constraints may

Table 7-1 Standard Cross-Section by ADT

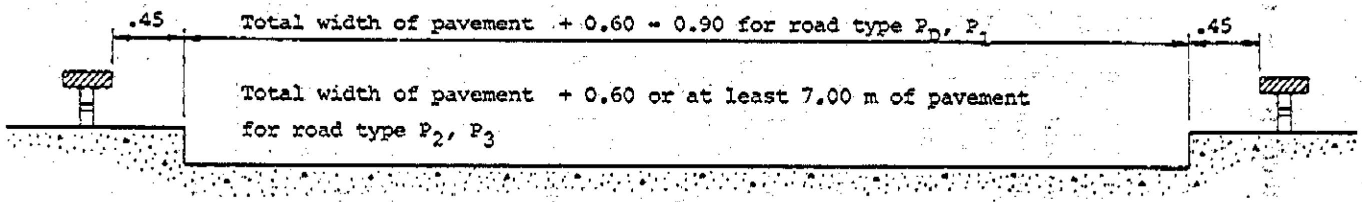
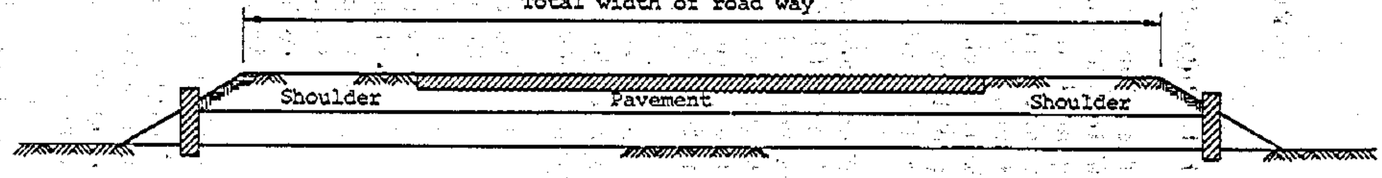
Daily Traffic Volume (ADT)	P_D more than 20,000	P_D 4,000	P_1 750–4,000	P_2 300–750	P_2 less than 300	P_3 not over 200
Width of Pavement (m)	21.00	14.00	7.00	650-7.00	6.00-7.00	6.00
Shoulder (m)	3.00	3.00	250-3.00	250	2.00	1.00-200
Minimum Right of Way (m)	60.00	40.00	30.00	30.00	30.00	20.00
Speed km/hr	96	160	80	120	50	96
Max. percent of slope	3	4	5	6	6	7
Horizontal Curve	3°	3°	4°	5°	6°	8°-24°
Sight Distance (m)	300	300	250	250	180	150
Type of Pavement	High class	Reinforced concrete Hot mixed asphalt		Medium class	Reinforced concrete Asphaltic pavement	Asphaltic pavement
Width of Pavement on a bridge longer than 6.00 m	 CROSS SECTION OF BRIDGE					
Width of Pavement in the Section of Road on Ground	 CROSS SECTION OF ROAD WHICH HAS A CULVERT					

Table 7-2 Recommended Cross-Section Dimension for Different Land Use

Description	Residential Area			Commercial Area		Industrial Area
	Low Density	Medium Density	High Density	Secondary	Primary	
Shoulder	2.00	2.00	2.40-3.00	2.40-3.00	3.00	3.00
Side Walk	1.20-2.00	2.00	3.00-5.00	4.00-5.00	5.00-9.00	3.50-5.00
Parallel Parking Lane	2.00	2.00-2.50	2.50-3.00	2.50-3.00	3.00	3.00
Traffic Lane	2.75-3.00	3.00-3.25	3.25-3.50	3.25-3.50	3.50	3.50-4.00
Median	0.00-2.00	0.00-2.00	2.00-5.00	2.00-5.00	5.00	5.00-8.00
Bicycle Lane	2.50	2.50	2.50	2.50	2.50	2.50

prohibit the desired dimension, therefore transport planner may make his own judgment to modify the standard cross-sections.

In applying these guidelines for the planning of future transport system, the planner exercises two types of prescription: improvement of existing road; and construction of new segments. In both cases, existing projects need to be taken into consideration.

Prescription of ameliorating 'missing links' often involves the proposal for bridges. The location of new bridges to be constructed in the future, and the proposal for reconstructing existing bridge are the part of planning specification made in the General Plan.

Transport terminals such as bus/coach terminals are also a part of the general plan, but this is made by Department of Land Transport. Railway stations are planned by Railway Authority of Thailand. Traffic management is arranged by Traffic Police. Bus route is planned by Department of Land Transport.

Transport Development Framework

Transport projects planned by Department of Highways, Public Works Department and studies conducted by other government agencies are reviewed to identify priority projects that need to be incorporated in the General Plan.

Design of General Plan requires specification of road network leading to neighbouring cities, towns and villages. These links are usually Department of Highways (DOH) roads; their future dimensions are planned by the Department of Highways. The remaining inter-city highways may have to be planned within the General Plan, therefore the relationship between these neighbouring establishments has to be summarized to give highway development framework.

Land Use Constraints

Road space in urban area is one type of land use, and the road cannot be constructed without considering constraints such as:

- Reserved land (e.g. military reserve)
- Historic area
- Topographic condition
- Built-up area

Consideration should also be given to:

1. The feasibility of the plan: land ownership, buildings to be pulled down as the result of road improvements.

2. The relationship between highway network and land use in order to provide balanced development so as not to deteriorate urban amenity particularly in the vicinity of:

    - hospitals
    - old-age homes

- schools
- residential area
- religious places (such as Wats and monastery)

It is recommended not to construct main roads along these land uses and to provide a quality environment free from traffic noise, air pollution and vibration due to heavy trucks.

3. Safety is aimed for by restricting through traffic from residential area and putting emphasis on local traffic in this type of land use. It is also recommended to provide additional access roads immediately next to schools when they front to busy traffic and school children are exposed to the risk of traffic accidents. Getting in or out of vehicles can be done in the lower-traffic access road.

The following sections describe the guidelines for: road network design; planning for buses; transport terminals and other modes of transport; and traffic management measures.

7.2 Road Network Design

7.2.1 Urban Structure and Network Patterns

Urban Structure

Transport network provides basic structure to city development, and an appropriate strategy is essential to guide the future growth of the city so as to minimize transport and environmental problems, and to provide maximum mobility within urban area. There are basically three types of pattern; grid, ring & radial and linear of the component patterns.

Grid pattern. is most common in Thai cities where old city centers were extended to expand the urban area (e.g. Fig. 7.1). This pattern is suitable for distributing traffic evenly over an urban area, and provides alternative channels to all directions of O-D patterns, but the construction of grid roads are costly and generate many intersections which reduces the traffic circulation efficiency. Through traffic is usually distributed over the grid and there is a chance that the local traffic will conflict with the through traffic unless main streets are sufficiently wide to accommodate both types of traffic.

Ring & radial pattern. is more practical solution to cope with the growing demand of urban traffic (e.g. Figure 7.3). The through traffic can by-path the city center by using a ring road, and the traffic to nearby population centers is channeled into radial roads directly connecting those centers. The construction of ring-roads at the urban fringe is relatively easy for small to medium Thai cities, and it encourages even development over the urban area, which compensates for the concentric development that can result from radial roads.

Linear pattern. is also common for small cities which have developed along major highways passing through those cities. (e.g. Fig. 7.2). As local and through traffic build up, a by-pass route is often required and the road system could gradually develop toward a more extensive grid pattern.

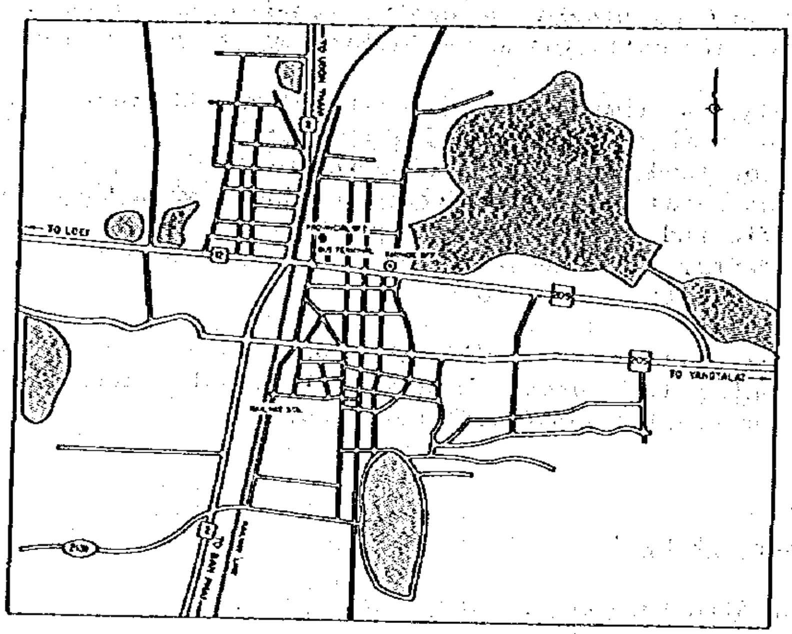


Fig. 7-1 Example of Grid Network (Khon Kaen)

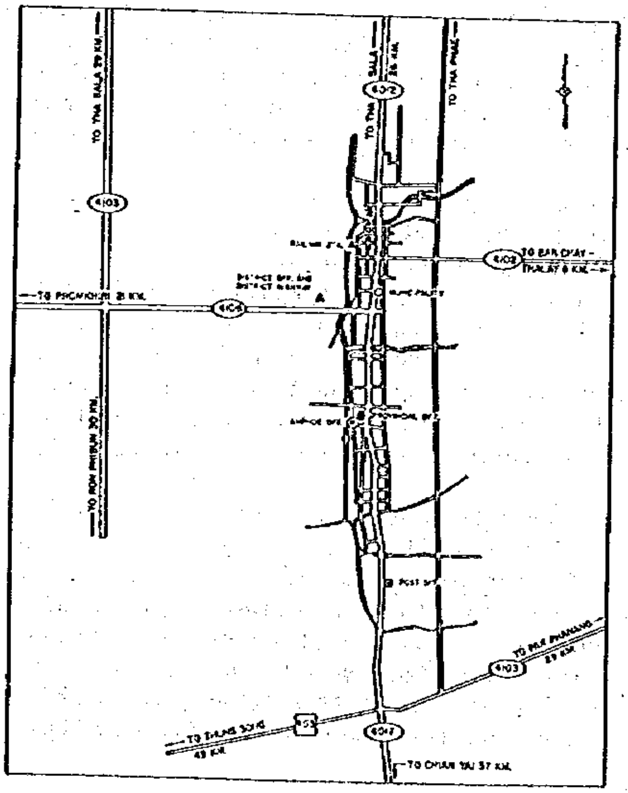


Fig. 7-2 Example of Linear Development (Nakhon Si Thammarat)

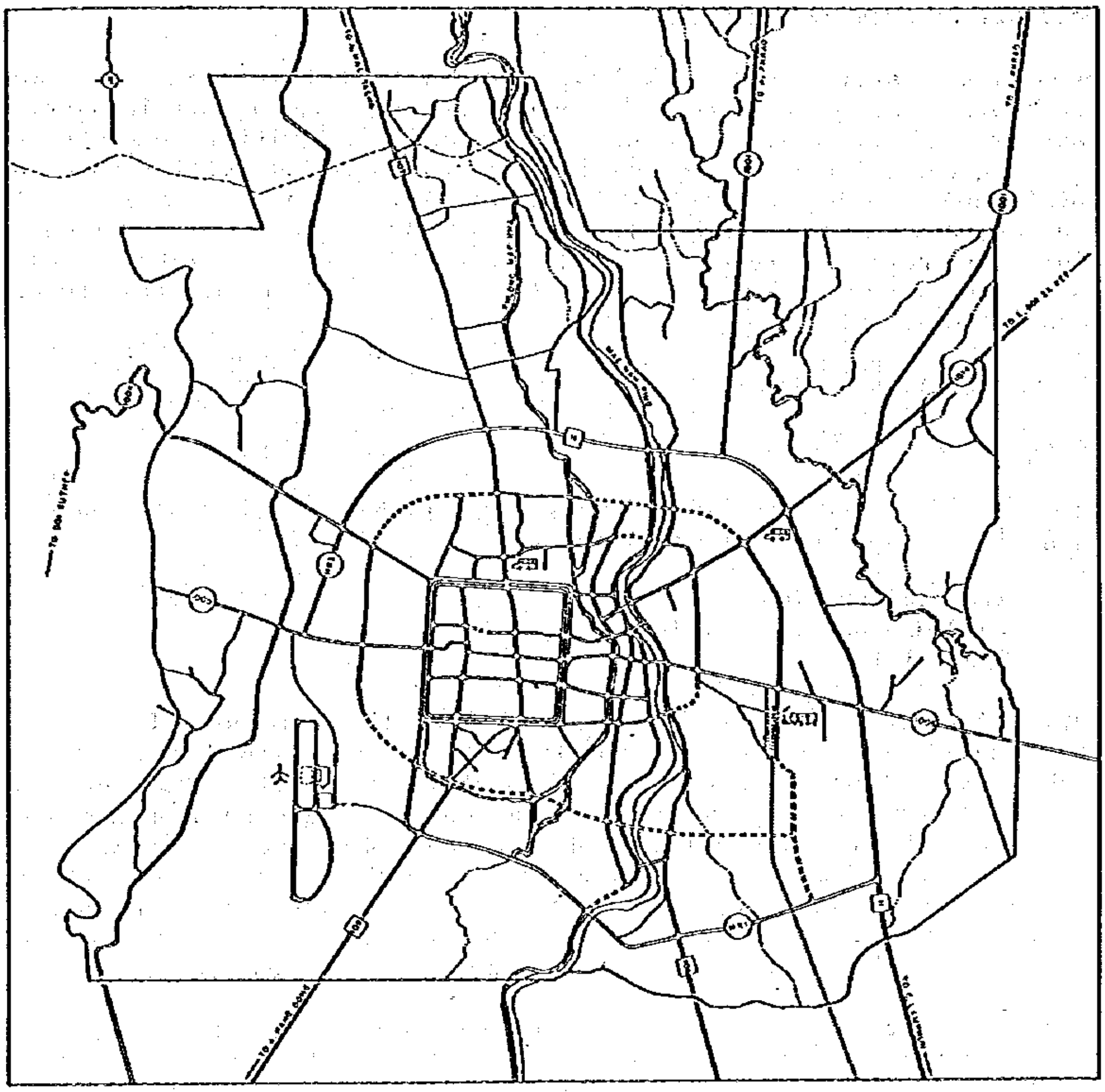


Fig. 7-3 Example of Network Development (Grid in City Center and Ring & Radial for outer area - Chiang Mai)

Local Street Network Patterns

Local scale street patterns have two basic categories; grid and branching. The grid pattern is suited for commercial and industrial areas as well as other areas where city center activities concentrate. Branching (or <u>Cul-De-Sac</u>) pattern is most common in Thai cities known as 'Sois', and suitable in residential areas where a quiet environment is required, but the branching system is not suitable for city area where major commercial activities are encouraged. In the latter case, connection of sois or road extension is prescribed in the future transport plan.

7.2.2 <u>Functions of Road</u>

Functions of Road

Roads in urban area perform a variety of roles. Their roles can be categorized into the following three types:

- Traffic function;
- Land use development function; and
- Spatial function.

<u>*Traffic Function*</u>. is mainly concerned with the movement of traffic. Roads and streets provide the mobility of getting around the city to reach various land use activities. The traffic function, however, may be further divided into two types: the function which puts emphasis on higher speed and capacity; and the function which focuses on accessibility to land use and buildings, in which the speed and capacity consideration is less important. The term 'traffic function' can be redefined to carry specific meaning defined in the former type of function. The latter function can then be called 'access function'.

Depending on the hierarchy of roads, the proportion of traffic and access functions changes as shown in Figure 7-4 and Figure 7-5. Table 7-3 shows the hiearchical classification of roads and their function used in the general plan.

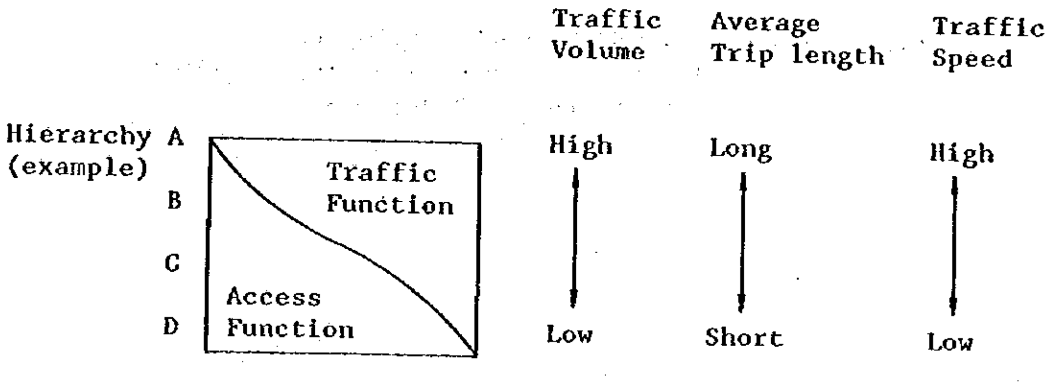


Figure 7-4 Road Hierarchy and Functions

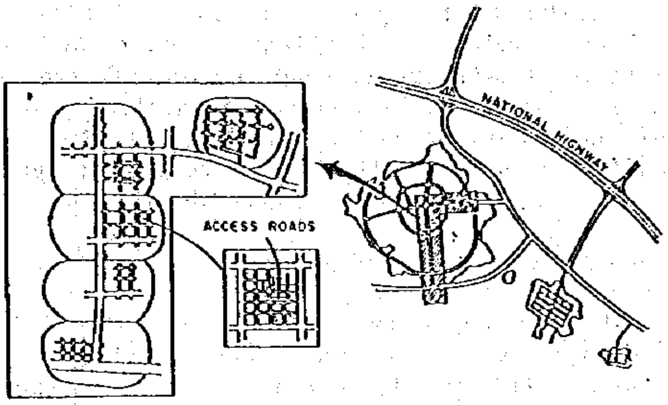


Figure 7-5 Concept of Road Hierarchy and Function

Table 7-3 Hierarchy of Roads Considered in General Plan

Functional Class	Functions
RURAL HIGHWAYS:	Connect provinces and regional cities forming national network. Provide high volume of traffic movement with relatively high speed.
URBAN HIGHWAYS:	
Primary Distributors*	Major trunk road in the area, that lead to rural highways.
District Distributors*	Distribute the traffic on primary distributors to major land use activities such as industrial area, and commercial centers.
Local Distributors*	Link between district distributors with access road and provide some direct access to less traffic-intense land use.
Access Road	Provide the distribution of traffic within particular land use such as residential area and connect to local distributors. The emphasis is on integration with land use and the speed of movement is disregarded.

Note : * marked roads are the main concerns of General Plan

Land-use development function. Construction of new road or improvement of existing network improves accessibility of the surrounding land area and promotes land use development. This function can be used to guide city development. The road constructed for this purpose is sometimes called 'development road'.

Spatial function. Urban road space also plays various roles that are essential to maintain urban activities. Roads and streets provide physical delineation of different land uses, and are used to channel electric and water supply as well as communication lines. This function is, however, of somewhat secondary importance in highway planning whereas the traffic function and the development guidance function explained above are the most important considerations.

Design Volume and Capacity Specification

The concept of highway capacity and design volume is important in highway network design especially when quantitative demand forecasting method is adopted. Estimated traffic volume on specific link is compared with link capacity and the degree of possible congestion is calculated. Observed traffic volume is usually expressed in 'annual average daily traffic (ADDT)' but the specification of link capacity is made by 'hourly design volume (HDV)'.

Design volume is determined to meet most of the traffic situation which take place throughout the year. Based on the continuous observation for one year (8,760 hours), hourly traffic volume is sorted out in descending order (see Figure 7-6).

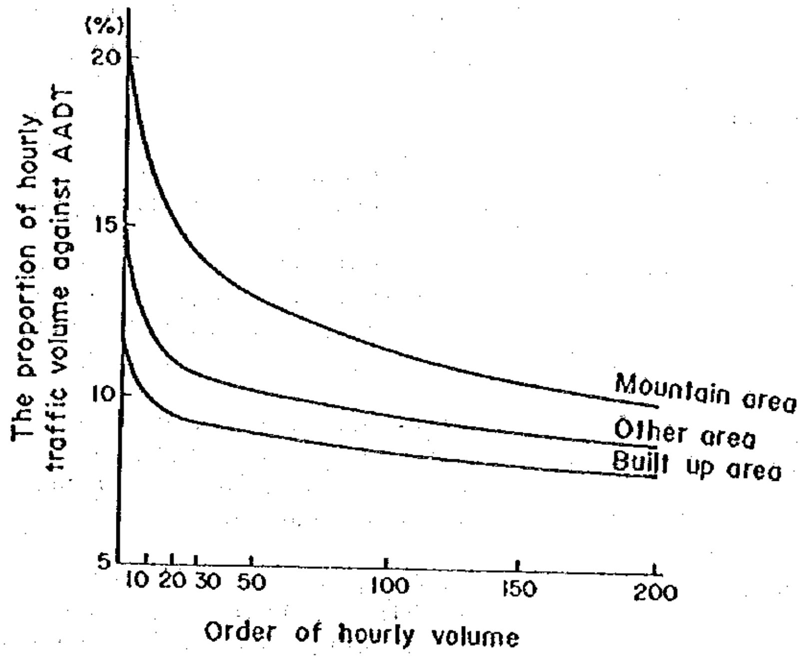


Figure 7-6 Ordering of Hourly Traffic Volume (Japanese Example)
(Source : JRF, 1984)

In general, the traffic volume decreases at a noticeable rate, but after about the 30th to 50th hourly volume it becomes less noticeable. This indicates that, if the 30th hourly traffic volume is taken as design volume, transport investment becomes very economical.

The conversion of AADT to hourly design volume is made by using K-factor, which is the proportion (in percent) of the 30th highest hourly traffic volume against AADT. Japanese example of K-factor and AADT are tabulated in Table 7-4, based on about 450 permanent survey stations.
Hourly Design Traffic = AADT x

Table 7-4 Trends of K-Factor and AADT (Japanese Example) - 1980

Road Classification	AADT	K-Factor
Build up (arterial)	33,471	7.6 %
Build up (others)	42,602	8.2 %
Rural (arterial)	23,923	8.5 %
Rural (arterial mountains)	11,893	9.6 %
Tourism	8,709	15.5 %
Average	24,430	9.7 %

If the traffic assignment is conducted on an AADT basis, K-factor is used to convert the results into hourly traffic volume. Alternatively, if hourly volume is used in an assignment the unit of O-D matrix should be adjusted to represent the 30th hourly traffic volume by using K-factor.

7.2.3 Road Density and Accessibility

One of the major objectives of the highway planning is to improve accessibility which can be defined as the degree of ease to reach land use activities distributed over space. The level of accessibility, then, is improved by overcoming the distance between different land use percels. Average spacing of roads or road density (km/km^2, km^2/km^2) can serve as an indicator of accessibility. The total length or area of road per unit population is also used in Japan.

Different land uses require different degrees of road development. Commercial land use requires, for example, a more finer road network than residential or industrial land uses. The formula used for this calculation can be shown as follows:

$$L = r \times A - L_o$$

where L : required road length (km)
r : adequate road density (km/km^2)
A : planning area (km)
L_o : existing road length (km)

The road density can be standardized for different land use categories.

Table 7-5 shows the road density (km/km^2) used in Japan for arterial roads with more than 4 lanes. Table 7-6 is the street spacing guideline in Tokyo for different land use.

Table 7-5 Road Density of Arterial Roads (with more than 4 lanes)

Size of City	Road Density by Land Use Type (Km/Km^2)		
	Residential	Commercial	Industrial
Large city (pop.: 1 mil. and over)	2 ~ 4	5 ~ 10	2 ~ 4
Medium city (pop.: 500,000 to 1 mil.)	2 ~ 4	4 ~ 8	2 ~ 4
Small city (pop.: 500,000 and under)	2 ~ 4	3 ~ 6	2 ~ 4

Table 7-6 Street Spacing Guideline in Tokyo

Area Classification	Spacing between networks (m)
High-density residential area	500 ~ 700
Medium-density residential area	700 ~ 900
Low-density residential area	1,000 ~ 1,300
CBD	400 ~ 700
Area mixed with residences, commerce and industry	500 ~ 1,000

7.3 Planning for Buses

Role of Bus Transport

Buses play an important role as public transport in urban areas especially when fixed track system (such as railway, light rail transit (LRT) is not available. The importance of bus transport seems to remain in most Thai cities regardless of the increasing private car ownership. Buses contribute to efficient use of urban road space and provide indispensable means of mobility to those without access to private cars.

There are a variety of types of buses operating in Thailand ranging from: 1 to 5 passenger carrying taxi-like minibuses by using pick up van, which is being operated in Chiang Mai; and to 80 to 90 seater long-distance buses operating between provincial cities. Standard stage buses have capacity of 60 to 90 passengers.

The characteristics of bus problems are somewhat different among cities. Bigger cities face decreases of speed and reliability due to traffic congestion; this encourages passengers to shift to private cars, and decreased patronage endangers the profitability which reflects on decreased service level. Smaller cities are also facing decreasing patronage due to increasing car ownership. Nevertheless bus transport is indispensable to 'transport disadvantaged'[1] population.

Bus Route Planning

One of the most important measures in a bus improvement program is the bus route planning. Bus routes are usually determined by bus operators based on profit maximizing point of view, but there are some theories to work out optimum bus routes and their frequencies. An example work flow based on such theories is shown in Figure 7-7.

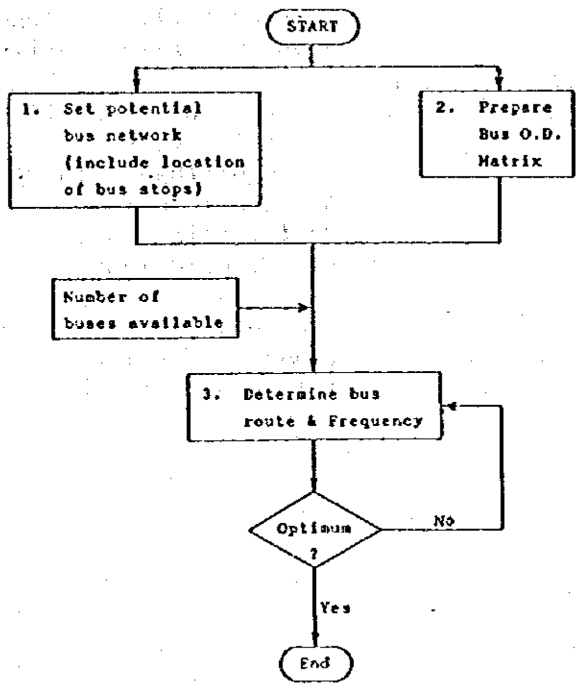


Figure 7-7 Process of Bus Route Planning

[1] 'Transport disadvantaged people' are those people who usually do not have access to private cars.

1. Set potential bus network including location of bus stops.

2. Prepare bus passenger O-D matrix based on person trip survey or bus passenger questionnaire survey.

3. Determine optimum bus route and frequency system.

The problem of setting optimum bus route and frequency is one of solving and sorting out a set of conflicting situations. Good bus route system minimizes the passengers' need to change the buses and this implies that such a system should consist of as many bus routes as O-D pairs. As the number of bus routes increase, however, the frequency of each bus route has to be reduced due to limited resource; and this will result in longer waiting time for passengers and the convenience of bus service will deteriorate. From the operators point of view bus route system needs to be sufficiently simple so as to improve operating efficiency and minimize the chance of running empty buses.

Related Bus Improvement Measures

Planning for buses require an coordinated approach other than bus route planning explained in the previous section. Related improvement measures are shown in Table 7-7.

Table 7-7 Related Bus Improvement Measures

Area of Improvement	Bus Improvement Measures
Bus Lane Improvement	Introduction of: - bus exclusive lane - bus priority lane - reverse flow arrangement - bus priority traffic signal
Bus Design	Improvement of performance: - acceleration - comfortable running Air Conditioning Comfortable Seats Low Floor Height
Bus Operation	Demand Responsive Operation Frequent Service Reliable Schedule

7.4 Transport Terminals and Other Modes of Transport

Urban transport system is composed of not only network but also terminals such as: airports, bus and truck terminals, railway stations, and docks and harbours. These terminals generate traffic and bring impacts on transport network. The location of these terminal facilities has to be balanced the spatial distribution of municipal functions and the capacity of transport network.

As was pointed out in Part 1, most of the transport terminals are the responsibilities of other central government agencies, but the transport planner should be familiar with their traffic generation characteristic, relation to other land use activities, and their locational impacts.

Airport

Airports are usually located at the urban fringe in Thai cities except in a few cases such as Ubon Thani. Airport generates both passenger and freight related traffic. The airport-related passengers have their other trip ends at most parts of the city area. The cities with big tourist industries have strong inter-relation between airport and city center where hotels are located. The air cargo tends to consist of low weight and high value commodities such as high-tech related industries. The related industries tends to locate near the airport.

Bus and Truck Terminals

In many cities bus terminals are located within CBD. The location is convenient for bus users who usually are able to find connecting means of transport easily. Market place is one of the most common land use that has been located near bus terminals in Thailand. As a result the streets around the bus terminals are often congested. It produces many pedestrian traffic in this situation, and the planner should be aware of pedestrian safety.

Truck terminals are generally located on the urban fringe along major trunk roads such as a national highway. Freight handled at the terminal is directly connected to factories, warehouses, and in certain cases, to railway stations, dock and sea-ports.

Railway Station

Railway transport provides both passenger and freight services. In most Thai cities, railway stations are usually located within the city and provide the passenger easier access to city center. In certain cities such as Chiang Mai the terminal is on the fringe of the city area, but buses and taxis connect to the city center. Cargo yard of rail freight may have strong connection to road and water transport system.

Docks and Harbours

Water transport has special significance for Thai cities which are located along rivers and canals. The cargo suited for water transport is also suited for rail and road transport, therefore the roads connecting these terminals may have high volume of heavy vehicles.

Planning for Other Mode of Transport

Consideration for other mode of transport is also important in certain cities. Related planning required for those cities include:

- Railway (fixed track) System Planning
- Cycle Path Planning

<u>Railway</u>. Railway or fixed track system is substantially more expensive to construct and operate compared with highway system. The key issue in railway planning is its economic and financial feasibility. Design of route and stations is predominantly guided by its technical feasibility and financial performance. For these reasons separate feasibility study is usually necessary.

<u>*Cycle Path*</u>. In certain cities of Thailand, the bicycle is an important mode of transport particularly for shorter journeys. Four types of accommodating bicycle track in Japan are shown in Figure 7-8.

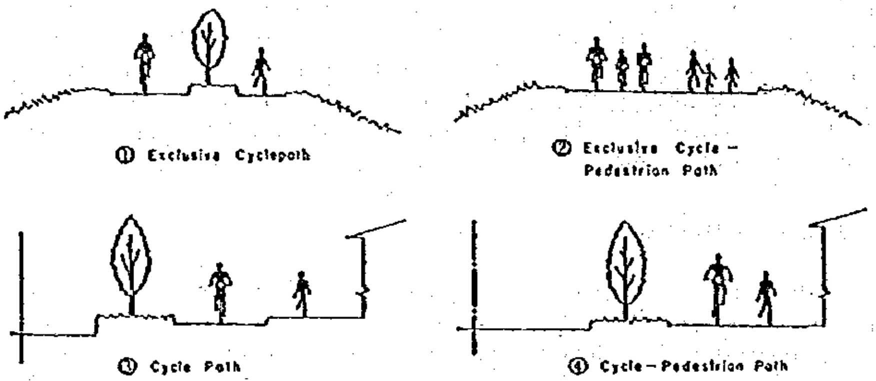


Figure 7-8 Cycle Path Based on Road Act, Japan

Cycle path should be considered for road with high bicycle traffic, and consider given to the following points.

- Continuity of cycle path
- Segregation with vehicular traffic

Exclusive cycle path is constructed mainly for recreational purposes in Japan.

7.5 <u>Traffic Management Measures</u>

Traffic management is a complementary measure of road network planning in urban areas. It promotes better use of urban road space. There is limitation in urban space, especially in City Center, and unlimited widening of city street is both impossible and impractical. The activities generally concentrated in city center and traffic demand is very high, but there is a need to reduce the traffic concentration; then, the use of private cars in the area has to be discouraged. Traffic congestion sometimes act as an impediment, but usually is not sufficient to reduce traffic flow.

World Bank in its policy paper[1] reviews transport policies of developing countries and examines the following measure as demand control. The list also shows the cities where those measures have been implemented.

- Road pricing, whereby motorists are charged for using congested roads (Hong Kong)

- Area licensing, whereby low-occupancy vehicles pay to enter congested city centers during rush hours (Singapore)

- Physical restraints to discourage the movement of private cars across city centers (Tunis and Goteborg)

- Parking controls to prevent long-term downtown parking by commuters but allow normal business activities (Singapore)

- User taxes on fuel to restrain the general use of vehicles (Republic of Korea)

- Financial restraints on vehicle ownership, such as high import duties, sales taxes, or annual licensing fees (Korea)

- Land use controls to influence the magnitude and type of transport demand (Curitiba and Bombay).

By focusing on the better use of existing streets and highways, the report introduces the following economical measures.

- Restrictions on parking, stopping, and street trading (San Jose and Lima)

- Priority measures for public transport vehicles, such as bus-only lanes and segregated rights-of-way (Bangkok)

- Better control of traffic movement-through such means as traffic signals and signs, intersection improvements, and pedestrian walkways-backed up by the enforcement of traffic regulations (Abid-jan)

- Road safety measures, including analysis of accident data, safe road design, inspection of motor vehicles, driver training and testing, and road user education (Brazil, Chile, and Costa Rica).

Implementation of the above listed measures requires coordination with related agencies such as traffic police, therefore careful assessment of their practicality should be made in the planning. Successful implementation of traffic management, however, has been able to achieve considerable savings in commuter journey times and vehicle operating costs, and especially in fuel consumption[2].

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[1] World Bank (1986), <u>Urban Transport, A World Bank Policy Study</u>, The International Bank for Reconstruction and Development/The World Bank, Washington: World Bank

[2] (ibid, P. ix)

PART 8:

Evaluation of Transport Plans

8.1 Evaluation Process in Transport Planning

Evaluation process has a close correlation with plan design process: Plan design process is guided by 'design requirements'; plan evaluation, on the other hand, is carried out by applying a set of 'evaluation criteria'. Both design requirements and evaluation criteria are drawn from common planning goals.

Evaluation of transport plan is the process of assessing the implication of proposed alternatives and measuring the expected impacts in terms of monetary values, or more broadly, social values. (See Fig. 8-1).

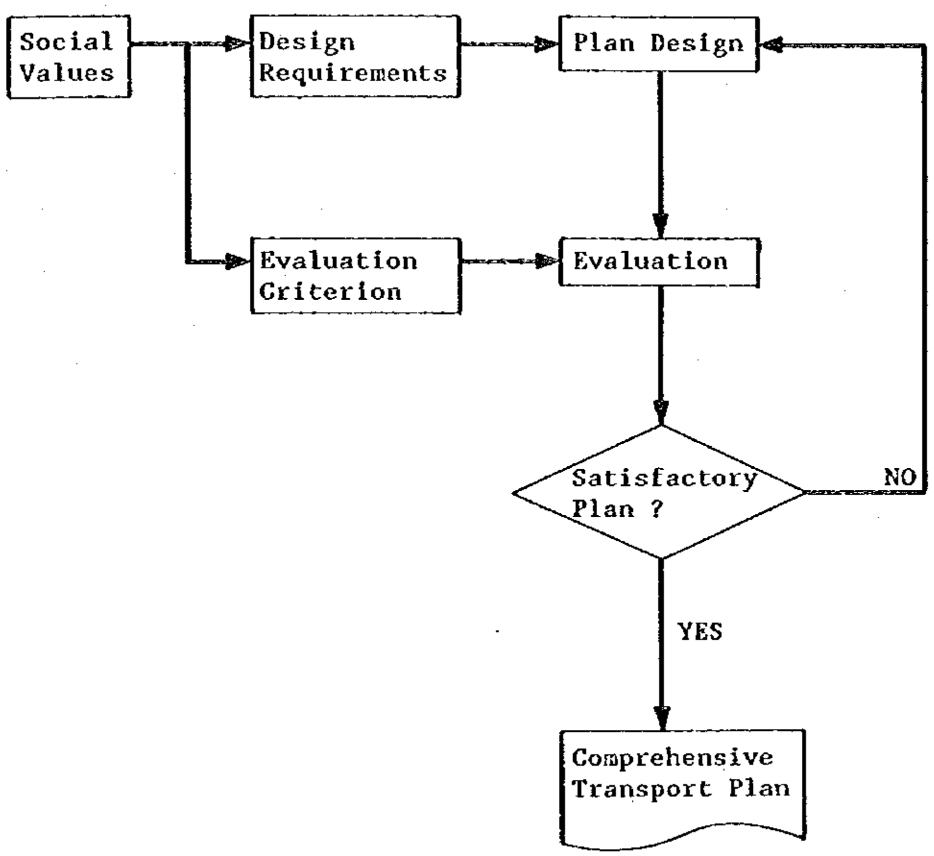

Figure 8-1 Evaluation Process and Its Relation to Social Values

There are three different situations in which evaluation of transport plans are conducted. The first type is 'comprehensive evaluation' approach in which a broad range of evaluation criteria, monetary or non-monetary, quantifiable or non-quantifiable, are taken into account. In this approach, the concept of 'value trade-off' is handled implicitly by