## 7. Model Runs - 10 Simulation Cases

### 7.1 Overview

A full model run requires that the starting point is the demographic spreadsheets established for the trip production and attraction sub models. In most cases the model run is started after the production and attraction development . The flowchart for a full future model run is shown in Fig. AP-1.12 . For BEIP ten full simulation cases were run in the development of the BEIP Transport Vision for Bangkok .

The major parameters in these case are network changes and demographic changes . Two future year demand scenarios are tested each with a different set of demographic data . Various networks are tested including changes in public transport which in some cases is reflected tested by modifying the road network . The changes are applied to the private person triptable which is then used to perform a new highway assignment. The basis of the analysis is that the initial private person trip table is changed as a result of modifications in the networks .

### 7.2 Person Trip Table

There are three base demand trip tables namely :

- Calibrated 1995 Person Trip Table ;
- 2011 Trend Person Trip Table ;
- 2011 New (Sub-Center Led) Person Trip Table

The demographic data used in the first two is tabulated by district in Table AP-1.2. The demographic data for the New 2011 changes only within the BMA as a result of the three sub-center developments at Lat Krabang/Minburi , Taling Chan and Bang Kungthian (see Table AP-1.16) .

### 7.3 Post Distribution Modal Split

The pre distribution mode splits were sufficient for the base year where the modal choice is not necessarily sensitive to changes in travel times between private and public modes . This is not sufficient to test major changes in either the public or private sector . For this reason modal diversion curves needed to be produced for this study . The previous modal diversion curves of SIMR were reviewed and accepted for BEIP .

The modal distribution curves used take the following format :

$$p = 1/(1 + \exp(A + B^*\Delta T + C^*\Delta + D^*N))$$

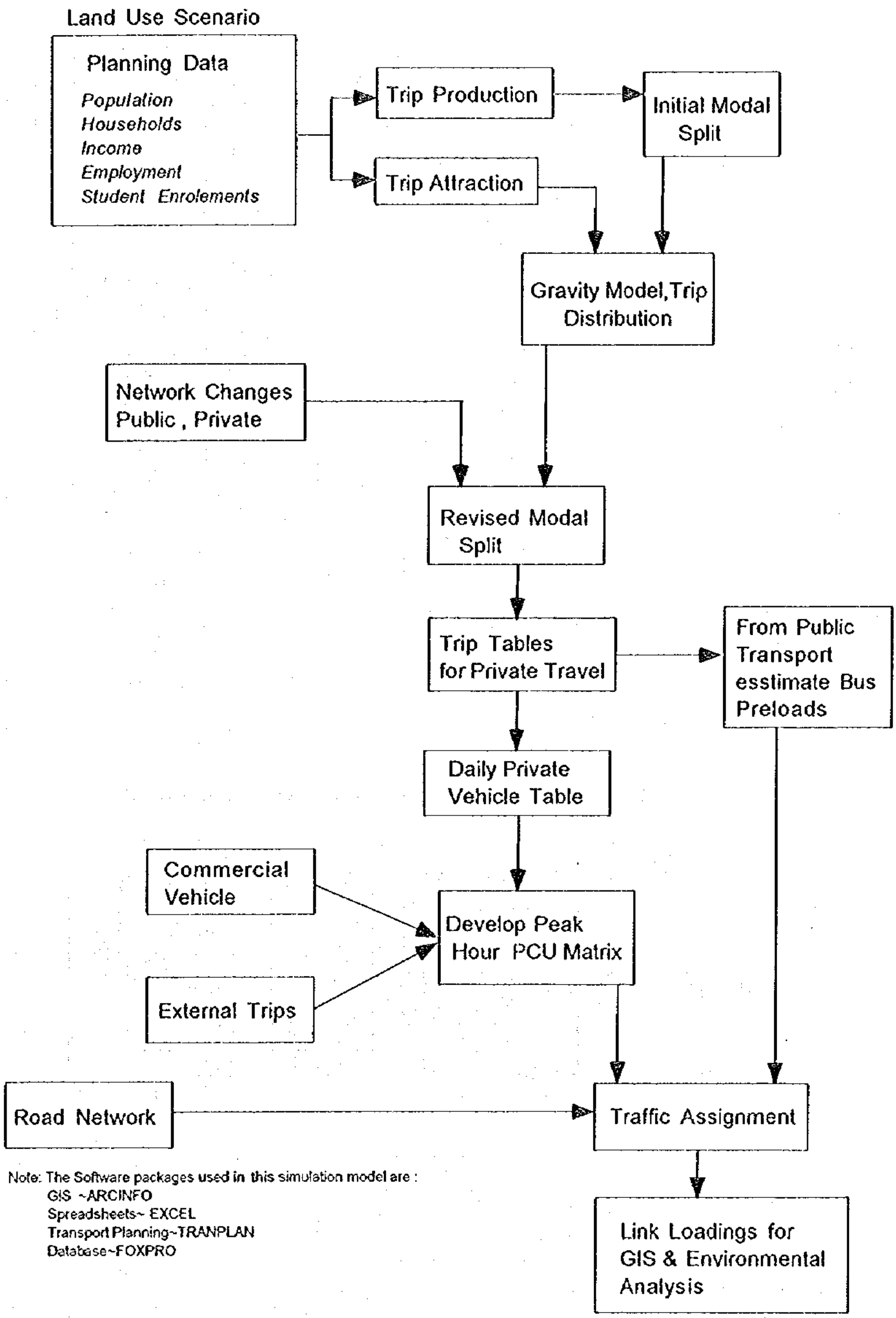
where p is the share of private mode

$\Delta T$ is the Travel Time Difference(Public-Private in minutes)

$\Delta C$ is the Travel Cost Difference(Public-Private in minutes)

N is the number of Interchanges

The parameter values are given in Table AP-1.17 and examples of the curves themselves are given in Fig. AP-1.13 & 1.14.




Note: The Software packages used in this simulation model are :
GIS ~ARCINFO
Spreadsheets~ EXCEL
Transport Planning~TRANPLAN
Database~FOXPRO

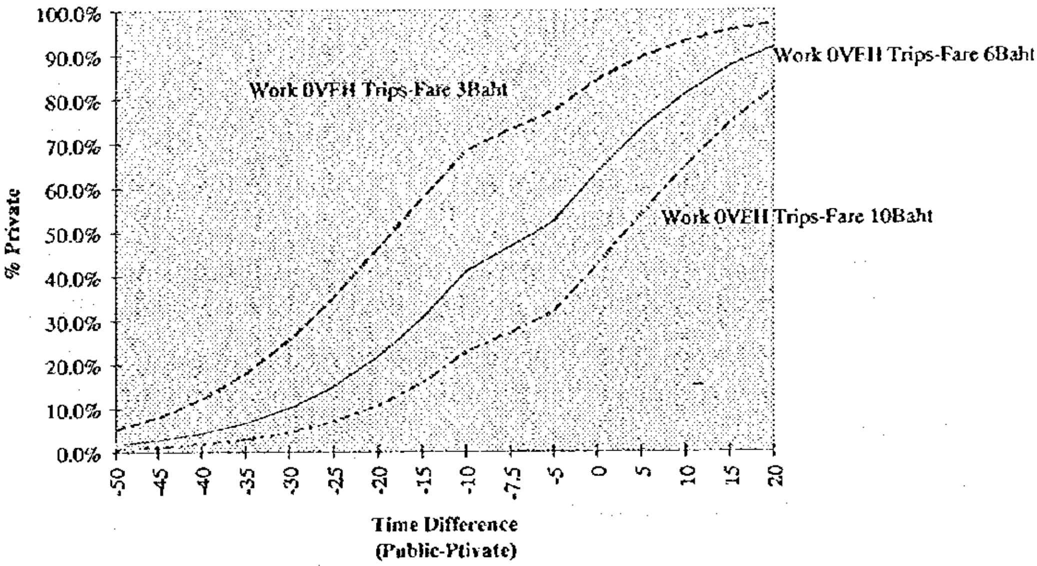
**Fig. AP-1.12 BEIP Similation Model Run**

## Table AP-1.16 Demographic Differences between trend-2011 and new-2011

| DISTRICT | Population | | HH Size | | Avg HH Income | | Employment Places | | Student Places | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Trend 2011 | New 2011 | Trend 2011 | New 2011 | Trend 2011 | New 2011 | Trend 2011 | New 2011 | Trend 2011 | New 2011 |
| Phra Nakhon | 107,190 | 107,009 | 4.02 | 4.01 | 44,048 | 44,114 | 301,928 | 274,754 | 71,075 | 69,984 |
| Pom Prap Sattruphai | 181,747 | 182,207 | 4.17 | 4.17 | 27,620 | 27,620 | 143,291 | 130,395 | 28,215 | 28,287 |
| Samphanthawong | 67,422 | 67,593 | 4.11 | 4.11 | 58,834 | 58,834 | 83,236 | 75,745 | 15,241 | 15,279 |
| Bangkok Noi | 308,989 | 305,721 | 3.90 | 3.90 | 24,819 | 24,821 | 59,973 | 58,653 | 60,519 | 60,566 |
| Bang Phlat | 301,047 | 301,808 | 3.81 | 3.81 | 31,448 | 31,448 | 125,852 | 123,083 | 49,097 | 49,221 |
| Khlong San | 167,473 | 167,898 | 4.12 | 4.12 | 29,736 | 29,736 | 105,743 | 103,417 | 18,254 | 18,300 |
| Thonburi | 343,068 | 343,938 | 3.35 | 3.95 | 24,114 | 24,114 | 115,151 | 112,617 | 56,143 | 56,285 |
| Bangkok Yai | 127,170 | 127,493 | 3.65 | 3.65 | 28,353 | 28,353 | 66,209 | 64,752 | 54,631 | 54,770 |
| Dusit | 282,910 | 283,600 | 3.67 | 3.67 | 36,260 | 35,260 | 124,549 | 121,809 | 115,296 | 115,549 |
| Bang Rak | 150,669 | 151,052 | 3.79 | 3.79 | 23,955 | 23,955 | 451,530 | 410,892 | 46,028 | 46,145 |
| Bang Kho Leam | 168,481 | 168,907 | 3.84 | 3.84 | 21,134 | 21,134 | 116,020 | 113,468 | 13,052 | 13,085 |
| Bang Sue | 404,365 | 405,391 | 3.58 | 3.58 | 37,222 | 37,222 | 109,689 | 107,276 | 50,403 | 50,531 |
| Pathumwan | 266,851 | 267,529 | 4.02 | 4.02 | 26,214 | 26,214 | 259,048 | 235,734 | 83,849 | 84,062 |
| Phaya Thai | 307,974 | 308,758 | 3.57 | 3.57 | 30,019 | 30,019 | 127,026 | 124,232 | 42,367 | 42,474 |
| Yan Nawa | 180,088 | 179,052 | 3.76 | 3.76 | 23,324 | 23,324 | 175,901 | 172,031 | 27,472 | 27,418 |
| Ratchathewi | 241,399 | 242,003 | 3.65 | 3.65 | 28,591 | 28,591 | 454,861 | 444,854 | 74,479 | 74,666 |
| Sathon | 161,532 | 161,942 | 3.72 | 3.72 | 27,764 | 27,764 | 206,506 | 201,963 | 67,280 | 67,451 |
| Klong Toei | 338,142 | 338,982 | 3.68 | 3.68 | 27,457 | 27,457 | 522,341 | 510,850 | 111,377 | 111,655 |
| Chatu Chak | 269,669 | 270,356 | 3.67 | 3.67 | 49,156 | 49,156 | 175,990 | 172,118 | 148,518 | 148,898 |
| Don Muang | 520,213 | 521,379 | 3.47 | 3.47 | 37,330 | 37,333 | 217,654 | 212,865 | 131,643 | 131,958 |
| Bang Kapi | 538,462 | 539,831 | 3.39 | 3.39 | 36,444 | 36,444 | 221,074 | 216,210 | 154,555 | 154,968 |
| Bang Khen | 420,802 | 421,873 | 3.42 | 3.42 | 37,406 | 37,406 | 68,640 | 67,130 | 64,553 | 64,717 |
| Bung Kum | 488,993 | 478,653 | 3.51 | 3.50 | 35,230 | 35,232 | 122,623 | 119,925 | 57,972 | 55,477 |
| Phra Khanong | 310,499 | 311,077 | 3.52 | 3.53 | 55,468 | 55,482 | 154,317 | 150,922 | 66,766 | 66,918 |
| Suan Luang | 282,459 | 283,174 | 3.55 | 3.55 | 45,022 | 45,022 | 80,631 | 78,857 | 44,631 | 44,744 |
| Prawet | 340,256 | 326,217 | 3.91 | 3.91 | 38,732 | 38,453 | 88,405 | 86,460 | 34,126 | 33,605 |
| Huai Khwang | 156,008 | 156,406 | 2.20 | 2.20 | 25,908 | 25,908 | 228,307 | 223,284 | 66,659 | 66,830 |
| Lat Phrao | 297,852 | 298,610 | 3.57 | 3.57 | 35,170 | 35,170 | 52,968 | 51,802 | 29,715 | 29,791 |
| Din Daeng | 242,888 | 243,506 | 3.57 | 3.57 | 26,607 | 26,607 | 116,320 | 113,761 | 66,973 | 67,143 |
| Minburi | 268,491 | 269,174 | 3.70 | 3.70 | 43,920 | 43,920 | 61,498 | 112,284 | 45,325 | 45,440 |
| Latkrabang | 160,370 | 222,969 | 3.76 | 3.89 | 23,638 | 23,827 | 42,813 | 75,144 | 42,149 | 52,168 |
| Nong Chok | 95,465 | 95,706 | 4.10 | 4.10 | 20,262 | 20,262 | 16,156 | 15,801 | 13,652 | 13,687 |
| Chom Thong | 306,122 | 305,512 | 3.80 | 3.79 | 24,739 | 24,712 | 81,862 | 80,061 | 35,963 | 35,949 |
| Taling Chan | 282,862 | 293,669 | 3.71 | 3.71 | 48,352 | 48,392 | 33,524 | 77,842 | 39,696 | 40,806 |
| Bang Khun Thian | 477,459 | 484,525 | 3.75 | 3.75 | 32,167 | 32,346 | 111,165 | 179,078 | 72,670 | 91,219 |
| Phasi Charoen | 438,888 | 407,263 | 3.76 | 3.76 | 19,697 | 20,024 | 199,421 | 201,693 | 128,752 | 98,507 |
| Ratburana | 325,158 | 286,966 | 3.95 | 3.94 | 40,327 | 36,459 | 53,839 | 52,655 | 48,866 | 44,988 |
| Nong Khaem | 166,520 | 168,240 | 3.65 | 3.66 | 44,872 | 43,978 | 91,834 | 92,682 | 41,408 | 42,791 |
| | | | | | | | | | | |
| TOTAL | 10,495,953 | 10,496,009 | 3.66 | 3.66 | 33,802 | 33,738 | 5,767,895 | 5,767,101 | 2,319,369 | 2,316,330 |

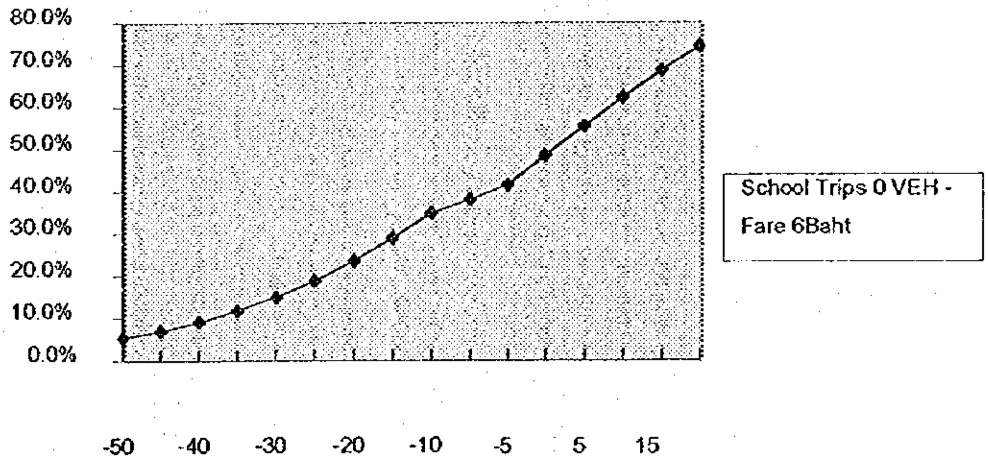
## Table AP-1.17 Parameters for Modal Split Diversion Curves

| Household Type | Purpose | A | B | C | D |
|---|---|---|---|---|---|
| Vehicle Available | HBW | -1.689 | -0.073 | -0.120 | -0.215 |
| | HBE | -0.070 | -0.162 | -0.382 | - |
| | HBO | -2.601 | -0.008 | -0.169 | -0.701 |
| | NHB | -1.103 | -0.093 | -0.302 | -0.254 |
| NO Vehicle Available | HBW | 1.148 | -0.092 | -0.284 | - |
| | HBE | 2.264 | -0.056 | -0.366 | - |
| | HBO | -1.101 | -0.010 | -0.165 | - |
| | NHB | 1.378 | -0.046 | -0.114 | - |




Fare difference : Three Fares as shown
No Interchange

**Fig. AP-1.13 Modal Diversion Curve for HBW No Vehicle Available**




Fare difference : Fares as shown
No Interchange

**Fig. AP-1.14 Modal Diversion Curve for HBE No Vehicle Available**

These modal diversion curves which are basically exponential curves had to be programmed into the transport modeling software package TRANPLAN .

The basic formula was of the following form for each test case:

T{Test}ij = T {Base}ij * [MS{Test}ij] / [MS{Base}ij]

where

T{Test}ij is the resulting number of private person trips for the test case.

T {Base}ij is the resulting number of private person trips for the base i.e. without major network changes.

MS{Test}ij is the modal split of private trips derived from using the private and public transport skims in the formula described above for modal diversion.

MS{Base}ij is the modal split of private trips derived from using the private and public transport skims in the formula described above for modal diversion.

## 7.4 Commercial and External Trip Growth

The future external and commercial vehicle trip tables were developed from the base year using the mathematical growth model known as Fratar . A set of expansion factors were developed for each trip type . In the case of the external stations these growth factors were developed from a review of trends in Department of Highway counts . The final factors are presented in Table AP-1.18

**Table AP-1.18 External Growth Factors**

| External Zone | Road Location | Annual Growth Factor ( % Per Annum) |
|---|---|---|
| 506 | Highway Route Number 35 | 6.0 % |
| 507 | Highway Route Number 4 | 6.0 % |
| 508 | Highway Route Number 346 | 6.0 % |
| 509 | Highway Route Number 321 | 3.0 % |
| 510 | Highway Route Number 340 | 3.0 % |
| 511 | Highway Route Number 3111 | 6.0 % |
| 512 | Highway Route Number 3309 | 6.0 % |
| 513 | Highway Route Number 1 | 3.0 % |
| 514 | Highway Route Number 32 | 6.0 % |
| 515 | Highway Route Number 3261 | 3.0 % |
| 516 | Highway Route Number 305 | 4.0 % |
| 517 | Highway Route Number 3312 | 6.0 % |
| 518 | Highway Route Number 304 | 6.0 % |
| 519 | Highway Route Number 34 | 6.0 % |
| 520 | Highway Route Number 3 | 6.0 % |

For commercial vehicles trips the growth factors were developed from the trip generation equations described in earlier sections of the appendix with an overall growth of 5 % per annum. This compares with a growth rate of 3 % per annum for mechanized trips (public plus private ). However in the so called do nothing scenario with no improvements to public transport and continual congestion there is expected to be a growth in private pcu vehicle trips of 5.4 % per annum in the morning peak hour .

It should also be remembered that the controlling number of trips in the peak hour assignment are the private vehicle trips which make up some 90% of all peak hour vehicle trips excluding public transport vehicles .

### 7.5 Ten Simulation Cases

For this project ten simulation cases were prepared in an attempt to clarify and refine the BEIP transport vision for Bangkok . The simulation cases have been devised to analyze policies rather than evaluate any of the individual road project put forward by individual agencies in the formulation of the 8 th national plan . The 10 cases are described in Table 19.

**Table AP-1.19 Ten Simulation Cases**

| | DEMAND | | | SUPPLY | | | SPECIAL POLICY |
|---|---|---|---|---|---|---|---|
| | 1995 | TREND 2011 | NEW 2011 | 1995 | 8th plan road | MRT | |
| CASE 1 | • | | | • | | | |
| CASE 2 | • | | | • | • | | |
| CASE 3 | • | | | • | • | • | |
| CASE 4 | | • | | • | | | |
| CASE 5 | | • | | • | • | | |
| CASE 6 | | • | | • | • | • | |
| CASE 7 | | • | | • | • | • | BUS PRIORITY |
| CASE 8 | | • | | • | • | • | ROAD CAPACITY INCREASE |
| CASE 9 | | • | | • | • | • | AREA RESTRAINT |
| CASE 10 | | | • | • | • | • | SUB CENTER DEVELOPMENT |

The difference between the two demographic projections is presented earlier in this appendix . The different trip making characteristics between 1995 and 2011 are shown in Table 20. The 8 th National Plan is described in detail in the main report. The MRT referred to in the above table is the mass transit master plan prepared by the CMIP team .

In all ten cases the simulation is done as in Fig. AP-1.14. The only exception being case 10 which also includes the redevelopment of trip generation with the New 2011 demographic data .

**Table AP-1.20 Demographic Assumptions**

| | BMA | | BMR | |
|---|---|---|---|---|
| Year | 1995 | 2011 | 1995 | 2011 |
| Population (x 1,000) | 8,126 | 10,495 | 11,453 | 15,227 |
| Households (x 1,000) | 2,037 | 2,870 | 2,858 | 4,145 |
| HH Size | 3.99 | 3.66 | 4.01 | 3.67 |
| Mechanized Trip per household | 6.79 | 7.80 | 6.29 | 6.97 |
| Average HH Income (Bahts / Month) | 21,032 | 33,802 | 20,081 | 32,437 |
| Household Vehicle Ownership | | | | |
| NONE | 42.5 % | 25.3 % | 38.9 % | 22.9 % |
| M/C | 21.8 % | 12.9 % | 23.5 % | 15.3 % |
| 1 CAR | 29.4 % | 44.6 % | 31.1 % | 45.7 % |
| 2 CAR | 6.3% | 17.2 % | 6.5% | 16.1 % |

For Cases 6-9 the simulation is based on certain assumptions to estimate the effect of particular policies . The mathematical assumptions to test the policies are as follows :

- Case7- The effect of increasing bus priority by giving over more road space to buses will increase private vehicle travel time.The simulation is to increase private travel time by 20 % . This is equivalent to decreasing the road space available to the private vehicle by 20%.
- 
- Case 8- The effect of increasing road space by 20% is achieved by increasing the capacity of all non expressway links by 20%.
- 
- Case 9- The policy of area restraint is tested by adding a toll on all links crossing the area bounded by the MRR on the east and the river on the west, equivalent to the toll on the First Stage Expressway toll .

The results from the analysis of the ten cases is presented in Table 21 in the form of the road congestion index by case whilst the major findings are summarized in Table AP-1.22. The interpretation of these results has helped in the clarification of the BEIP transport vision for BMA which can be summarized as follows:

- People movement is the Priority -Even if all the new roads are built with MRT by2011(Case 6) this will not be sufficient without bus priority (Case 7) or Area Restraint (Case 9) or Structural Change (Case 1).
- Many more roads are not the Answer Alone -In Case 8 , where additional road space is added without additional supporting public transport , the shift to the private mode does not match the increase in supply.
- New Road Development with Mass Transit and Improved Public Transport (All the analysis support this,to encourage the use of public
- Transport it may require area restraint in the form of central area restraint or changes in parking in the center(Case 9).

**Table AP-1.21 Results of Simulation Analysis: Congestion Ranking for Roads within BMA (% distribution of roads in morning peak hour)**

| LEVEL | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| SATURATED | 13.2 | 3.4 | 1.5 | 62.2 | 35.5 | 23.8 | 10.1 | 32.0 | 16.8 | 18.2 |
| HEAVILY CONGESTED | 15.7 | 6.0 | 3.8 | 13.2 | 14.6 | 13.8 | 14.1 | 13.2 | 14.8 | 13.3 |
| CONGESTED | 9.4 | 5.5 | 4.0 | 5.8 | 8.4 | 8.6 | 9.0 | 7.2 | 9.1 | 9.3 |
| **Sub -Total (km)** | **38.3 (663)** | **14.9 (354)** | **9.3 (219)** | **81.2 (1406)** | **58.5 (1389)** | **46.2 (1100)** | **33.2 (789)** | **52.4 (1246)** | **40.7 (965)** | **40.8 (971)** |
| **C.I.** | **100** | **39** | **24** | **212** | **152** | **121** | **87** | **137** | **106** | **106** |
| ACCEPTABLE | 12.6 | 10.1 | 8.0 | 5.8 | 10.4 | 10.3 | 11.5 | 9.8 | 11.9 | 11.5 |
| UNDER CAPACITY | 49.1 | 75.0 | 82.7 | 13.0 | 31.1 | 43.5 | 55.3 | 37.8 | 47.4 | 47.7 |
| TOTAL | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| LENGTH | 1732 | 2376 | 2376 | 1732 | 2376 | 2376 | 2376 | 2376 | 2376 | 2376 |

Note C.I. : Congestion Index (Based on Percentage of Congested Roads in 1995=100)

**Table AP-1.22 Major Findings from the Simulation Analysis**

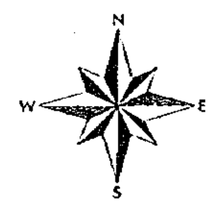
| CASE | C.I. | % PT | COMMENTS |
|---|---|---|---|
| 1 | 100 | 55 | The Existing Situation |
| 2 | 39 | 50 | If all the roads of the 8th plan were to built in 1995, the C.I. decreases to 39 |
| 3 | 24 | 60 | If Mass Transit were in place in 1995, the C.I. drops further as the modal chsre of public transport increases. |
| 4 | 212 | 55 | The "Do Nothing Case" by 2011<br>If nothing is done, the C.I increases significantry |
| 5 | 152 | 43 | The roads of the 8th plan in place by 2011, the C.I. decreases but not below 1995 level. Mmore road construction leads to decrease of public transport (PT) share. |
| 6 | 121 | 58 | Case 5 with the Mass Transit, C.I decreases but still above 1995 level. |
| 7 | 87 | 63 | In addition, "BUS PRIORITY" is added, C.I. becomes close to the existing level. |
| 8 | 137 | 48 | It was assumed more road space could be created at the local street level. This leads to a decrease of public transport (PT) share and increase of C.I. |
| 9 | 106 | 61 | With central area restraint (the Middle Ring Road in this case), public transport (PT) share and C.I. decreases. |
| 10 | 106 | 58 | With the sub-center development case, C.I. decreases in comparison with case 6. |

Fig. AP-1.15 Level of Congestion

# Level of Road Traffic Congestion (case1)

## Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity




SCALE 1:235000

5 0 2 4 6 8 10

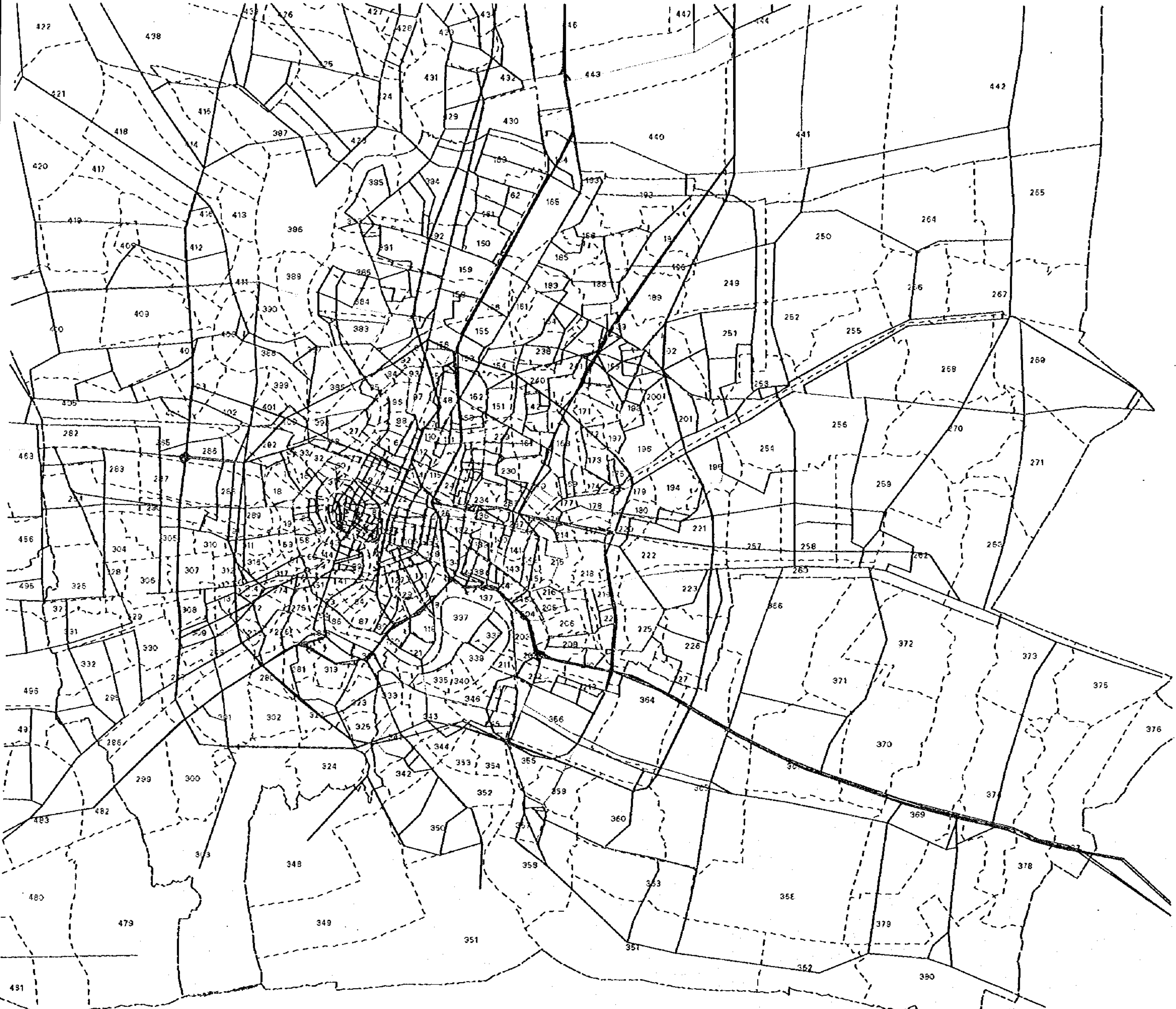
KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

Fig. AP-1.16 Level of Congestion



# Level of Road Traffic Congestion (case2)

## Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

N
W
E
S

SCALE 1:235000

6 0 2 4 6 8 10

KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JICA JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

Fig. AP-1.17 Level of Congestion

## Level of Road Traffic Congestion (case3)

### Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

N
W E
S

SCALE 1:235000

6 0 2 4 6 8 10

KILOMETERS

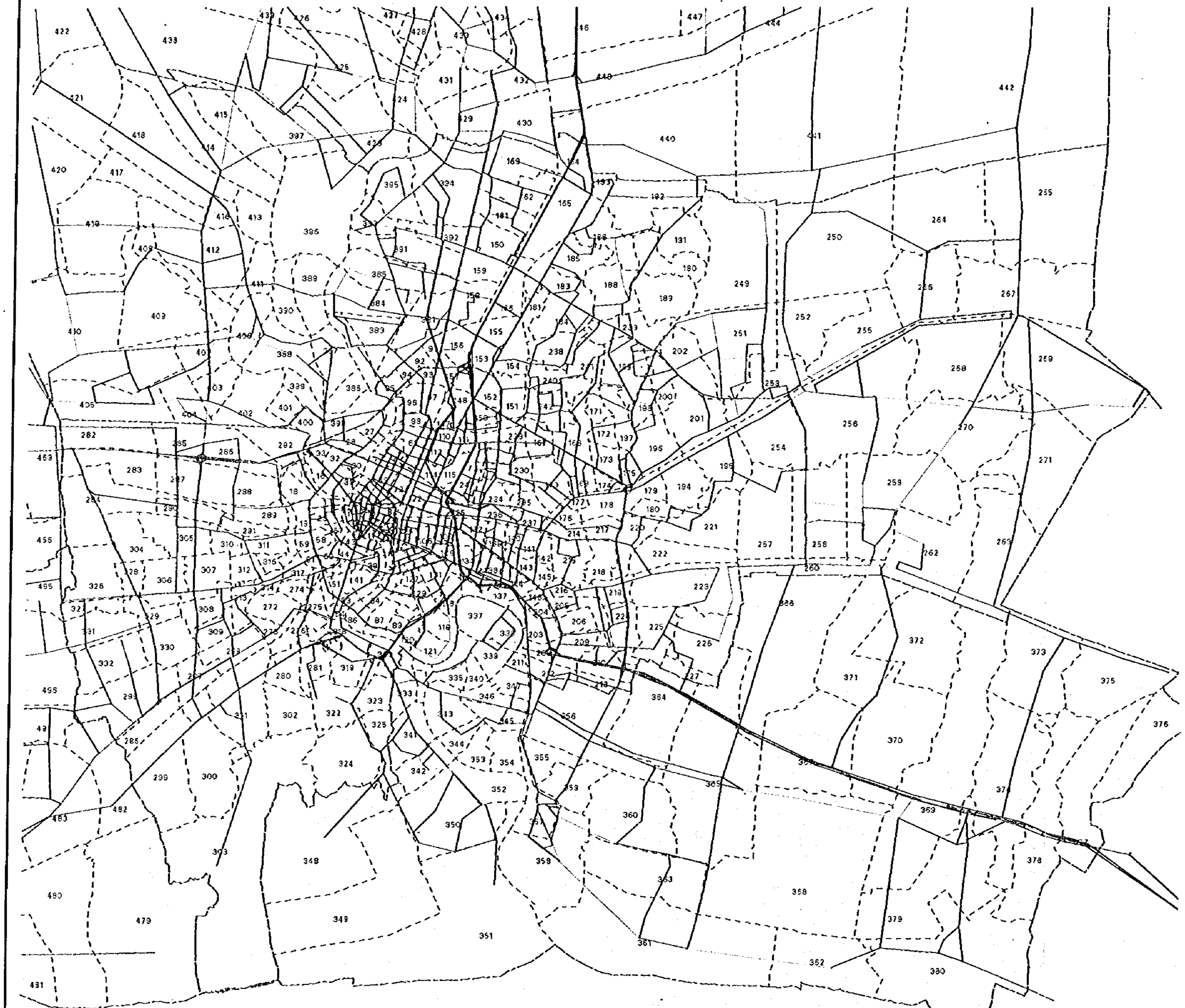
THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

Fig. AP-1.18 Level of Congestion

## Level of Road Traffic Congestion (case4)



### Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

SCALE 1:236000

5 0 2 4 6 8 10

KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

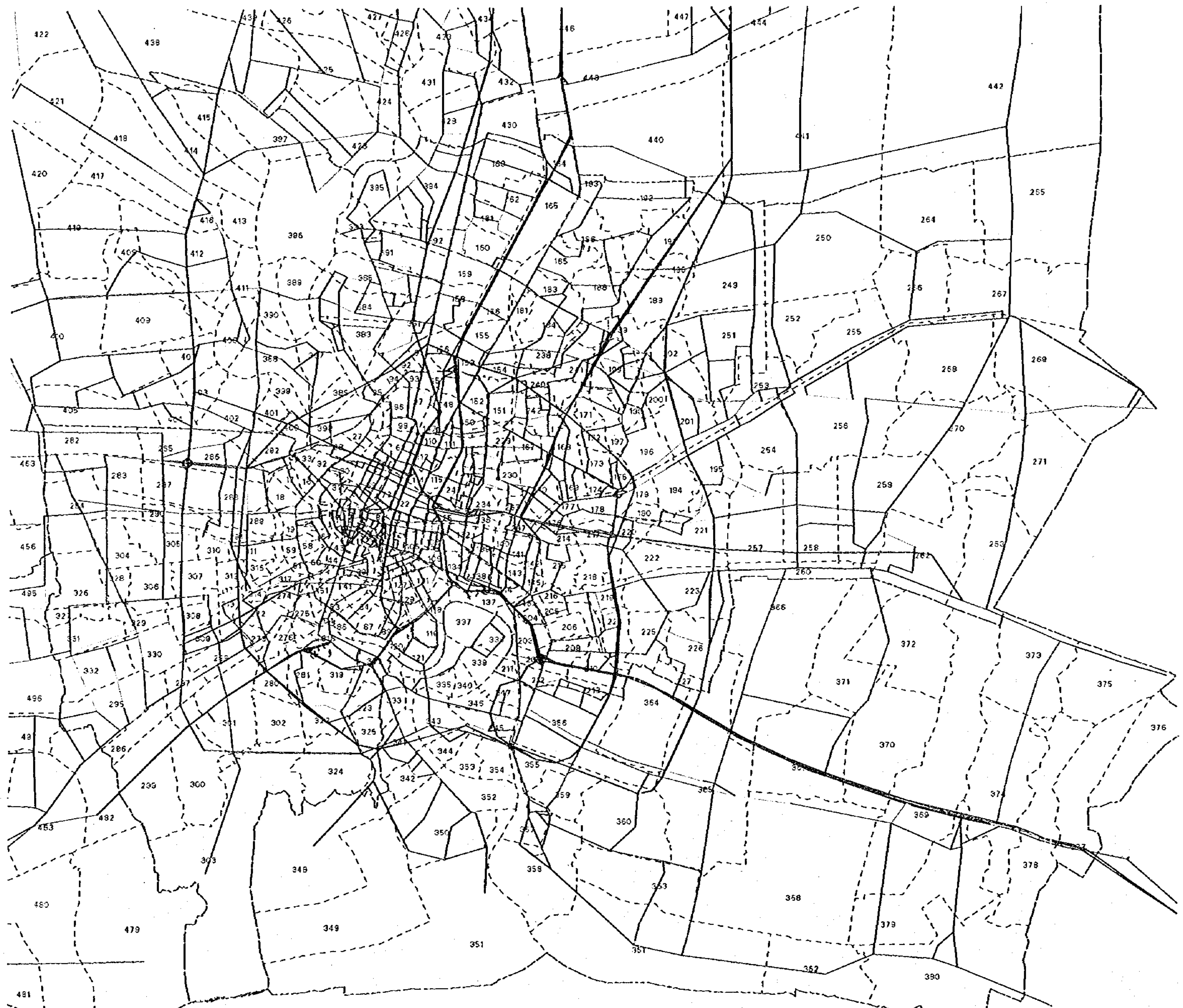
# Level of Road Traffic Congestion (case5)


THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

Fig. AP-1.20 Level of Congestion



# Level of Road Traffic Congestion (case6)

## Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

N
W E
S

SCALE 1:235000

5 0 2 4 6 8 10

KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

Fig. AP-1.21 Level of Congestion

## Level of Road Traffic Congestion (case7)

### Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

N
W E
S

SCALE 1:235000

5 0 2 4 6 8 10

KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

# Level of Road Traffic Congestion (case8)

## Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

SCALE 1:235000

5 0 2 4 6 8 10

KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

# Level of Road Traffic Congestion (case9)

## Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

N W E S

SCALE 1:235000

5 0 2 4 6 8 10

KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

Fig. AP-1.24 Level of Congestion

# Level of Road Traffic Congestion (case10)

## Legend

- Provincial Boundary
- Saturated
- Heavily Congested
- Congested
- Acceptable
- Under Capacity

N
W E
S

SCALE 1:235000

5 0 2 4 6 8 10

KILOMETERS

THE STUDY
ON
URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM
IN
BANGKOK METROPOLITAN AREA (BEIP)

BANGKOK METROPOLITAN ADMINISTRATION(BMA)
THE GOVERNMENT OF THE KINGDOM OF THAILAND

JAPAN INTERNATIONAL COOPERATION AGENCY(JICA)

## 7.6 Down Loading to GIS and Environmental Analysis

For additional analysis and environmental simulation , the output from the transport assignment program was dumped into an ASCII format and combined with selected items from the road inventory network databases to produce input data files into GIS software and the environmental package .

For further GIS analysis the link volume,volume capacity ratio ,the link rank (a function of the volume capacity ratio) were merged into a database file.

For input into the environmental program the link volume and link speeds from the peak hour pcu assignments broken down into several vehicle type by different time periods . The factors used in this process were developed from existing traffic counts and route choice speed surveys undertaken as part of UTDM.

## 7.7 Sample Run Procedure

A full run procedure with file names and instructions is presented in Table 23

**Table AP-1.23 Model Run Procedure for Case 7**

| PROGRAM NAME | TASK DESCRIPTION | INPUT FILES | DESCRIPTION | OUTPUT FILES |
|---|---|---|---|---|
| FUT12CA7.IN<br>(TRANPLAN) | Run Gravity Model | FUTSKIM.BIN<br>GFUT9.DAT<br>GFUT10.DAT | Future Skim Matrix<br>Future production & attraction files derived from modal split spreadsheets, MOD2011X.XLS | HBW11CA7.BIN<br>HBE11CA7.BIN<br>HBO11CA7.BIN<br>NHB11CA7.BIN |
| CA7HBW11.IN<br>CA7HBE11.IN<br>CA7HBO11.IN<br>CA7NHB11.IN<br>(TRANPLAN) | Modal Split Run for 4 purposes (Note, program is currently set to use Case 6 as starting point. To change edit 'new.mip' to 'ca7.bin') | PRSKMNEW.MAT<br>PRSKMOLD.MAT<br>PTSKMNEW.MAT<br>PTSKMNEW.MAT<br>HBW11CA7.BIN<br>HBE11CA7.BIN<br>HBO11CA7.BIN<br>NHB11CA7.BIN | Old & new private skims<br>Old & new public skims<br>Output matrices from Gravity Model Run | HBW11NEW.CA7<br>HBE11NEW.CA7<br>HBO11NEW.CA7<br>NHB11NEW.CA7 |
| CA714NEW.IN<br>(TRANPLAN) | Develop Daily Trips ~Split private trips between car and m/c . | FRATHBW.DAT<br>FRATHBE.DAT<br>FRATHBO.DAT<br>FRATNHB.DAT<br>HBW11NEW.CA7<br>HBE11NEW.CA7<br>HBO11NEW.CA7<br>NHB11NEW.CA7 | Private person split factors for car and motorcycle<br>Trip tables as output from the modal split procedure | DAY11NEW.CA7 |
| CA715NEW.IN<br>(TRANPLAN) | Peak hour PCU matrix for traffic assignment | DAY11NEW.MAT | Daily private matrix as output from previous step | HR11NEW.CA7 |
| C7_11_01.IN<br>(TRANPLAN) | Case 7 Assignment Loads 2011 triptable onto 2001 network | HR1111NEW.CA7<br>2001HW.NET<br>BEIEX11A.MAT<br>TRUCK11.MAT<br>TRANSIT.DAT<br>TURN_BAN.TXT | Peak Hour Private-2011<br>Network - 2001<br>Externals - 2011<br>Commercials - 2011<br>Bus Preloads<br>Turn ban file | CA711_01.LOD<br>(Loaded network for Case 7) |
| NETCARD<br>(TRANPLAN) | Dump for GIS<br>Options: Dump 2 way<br>Rounded speeds<br>Speed Factor-1<br>Output Cap1 in cap 2 field-no , with last iteration . | CA711_01.LOD | Loaded network for Case 7 | CA711_01.TXT |
| TRANLOD.PRG<br>(FOXPRO) | Procedure for GIS Program requires editing of input and output filenames. Edit CA7 to new case number | CA711_01.TXT | Dumped network in text format | CA711_01.DBF<br>(database file for input into ARCINFO) |
| ENVIRON.PRG<br>(FOXPRO) | Converts to environmental format Dump to text format using NETCARD but choose 1 way option. | Use this text file dumped from loaded network , Open file TRAN_LOD.DBF, then zap. Append text file. Then run program. | | TRAN_FIN.DBF<br>(Dump this file to text to transfer to environmental group for analysis) |
| PR_SKIM.IN<br>PU_SKIM.IN<br>PR_NEW.IN<br>PU_NEW.IN<br>ACC_SKIM.IN | Develops start private skim<br>Develops start public skim<br>Develops new private skim<br>Develops new public skim<br>Develops time skims for 10 cases for accessibility analysis | | | |

# APPENDIX 2: THE BEIP SIMULATION MODEL FOR AIR POLLUTION

## 1. Objectives of the BEIP Simulation Model for Air Pollution

The BEIP Simulation Model for Air Pollution is a simulation model modified to emulate the air pollution of Bangkok, as the BEIP Study Team developed it by checking the simulation results with the actual ambient monitoring results.

The targets of the model are as follows;

- Simulated air pollutants are PM-10, CO, $SO_2$, $NO_x$, and $NO_2$;
- Computerized value is annual arithmetic mean concentration;
- Pollutant sources are motor vehicles, thermal power plants, and households; and
- Target area of concentration calculation is BMA.

## 2. Methodology

The outline of the model is as follows:

- Meteorological data observed at ONEB Station in 1988 by JICA;
- CONCAWE Equation (CONCAWE, 1966) and Briggs Equation (Briggs, 1969) for the height of the plume rise;
- Gaussian Plume Equation and Gaussian Puff Equation for the dispersion model; and
- Monitoring results of CO were used for model improvement.

The simulation procedure is shown in Fig. AP-2.1.

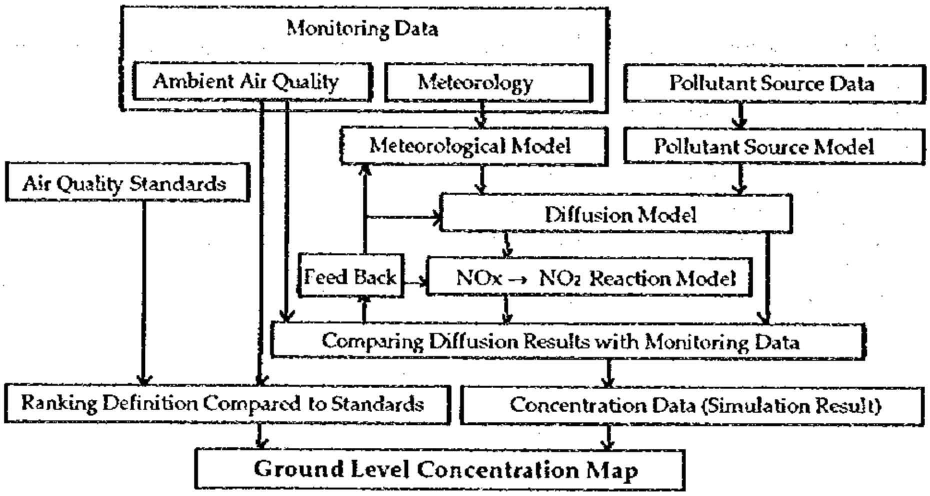



**Fig. AP-2.1 Flow Chart of Diffusion Simulation**

## 3. Target of the BEIP Simulation Model for Air Pollution

### 3.1 Target Years

The target year of present case is 1995, and 2011 for future case.

### 3.2 Air Pollutants Covered

Recently, PM-10 and CO are said to be important problems in Bangkok. $SO_2$ and $NO_2$ are potential important problems according to other countries experiences. So, concentration of primary PM-10, CO, $SO_2$, NOx and $NO_2$ are targets of this simulation model.

PM-10 consists of Primary PM-10 and Secondary PM-10. Primary PM-10 means PM-10 emitted originally from stacks and exhaust pipes. Secondary PM-10 means formulated PM-10 in the air from other air pollutants after emission from stack or exhaust pipe. Only primary PM-10 was simulated because PM-10 mainly consists of primary PM-10. Secondary PM-10 model also should be included to the simulation model if there are more available data enough to establish secondary PM-10 formulating model.

The quantity of SPM emitted from stack or exhaust pipe is assumed to be the amount of PM-10 although the definition of SPM sometimes may include larger particulate.

### 3.3 Averaging Time of Concentration

Long-term average (one year arithmetic mean) of concentration is calculated to omit hourly, daily and seasonally drifts and errors.

To simulate concentration of annual average, first, the meteorological information are grouped by matrix of 16 wind-directions, 8 ranks of wind-speed and 11 stability classifications, as described in Section AP2-4.4 for each matrix of three (3) seasons and four (4) time zones. Second, dispersion of pollutants per source is calculated for average condition of each matrix. Third, it is summarized to average concentration by each season-time zone. Finally, one (1) year arithmetic mean is calculated.

$$C_y = \sum_t \left( \sum_s \left( \sum_{rm} F(Q_s, W_{rm}) \cdot f_{rm} \right) \cdot f_t \right)$$

where

Cy: Yearly average of concentration
t: Matrix of Season and Time zone
s: Pollutant source
rm: Representative meteorology
F (): Dispersion equation
Qs: Quantity of pollutant from each source
Wrm: Meteorological information of each representative meteorology
frm: Frequency of each representative meteorology compared with each season and time zone
ft: Ratio of each time zone compared with one year

On the other hand, Simulation for short term, e.g., 1 hour average of concentration, is also necessary for the simulation under specified condition, e.g., analysis of high TSP concentration at Saphan Kwai monitored at temporally station in 1995. For this purpose, further study is required.

### 3.4 Pollutants Sources

Pollutants from motor vehicles and household were originally simulated because the study focuses the air pollution of Bangkok City. After the analysis of air pollutant sources in and around Bangkok, pollutants from thermal power plants in and near from Bangkok are found to be much important than those from household. So, emission from vehicles, household and power plants (South Bangkok Power Plant and North Bangkok Power Plant) are taken into account in this study.

### 3.5 Area of simulation

Area of simulation is whole area inside BMA (66 km in east-west direction and 52 km in north-south direction). Calculated points are nearly 4000, which are;

- 2m high at PCD's Monitoring Points;
- 1.5m high at 500m x 500m grid centers of inner Bangkok (West end is nearly Thanon Wongwan Rob Nok and east end is nearly Thanon Sinakarin, 2988 points); and
- 1.5m high at 1 km x 1 km grid centers of outer Bangkok (961 points).

The area of 500m grid cells is hatched area in Fig. AP-2.2, and the area of 1 km grid cells is other enclosed area.

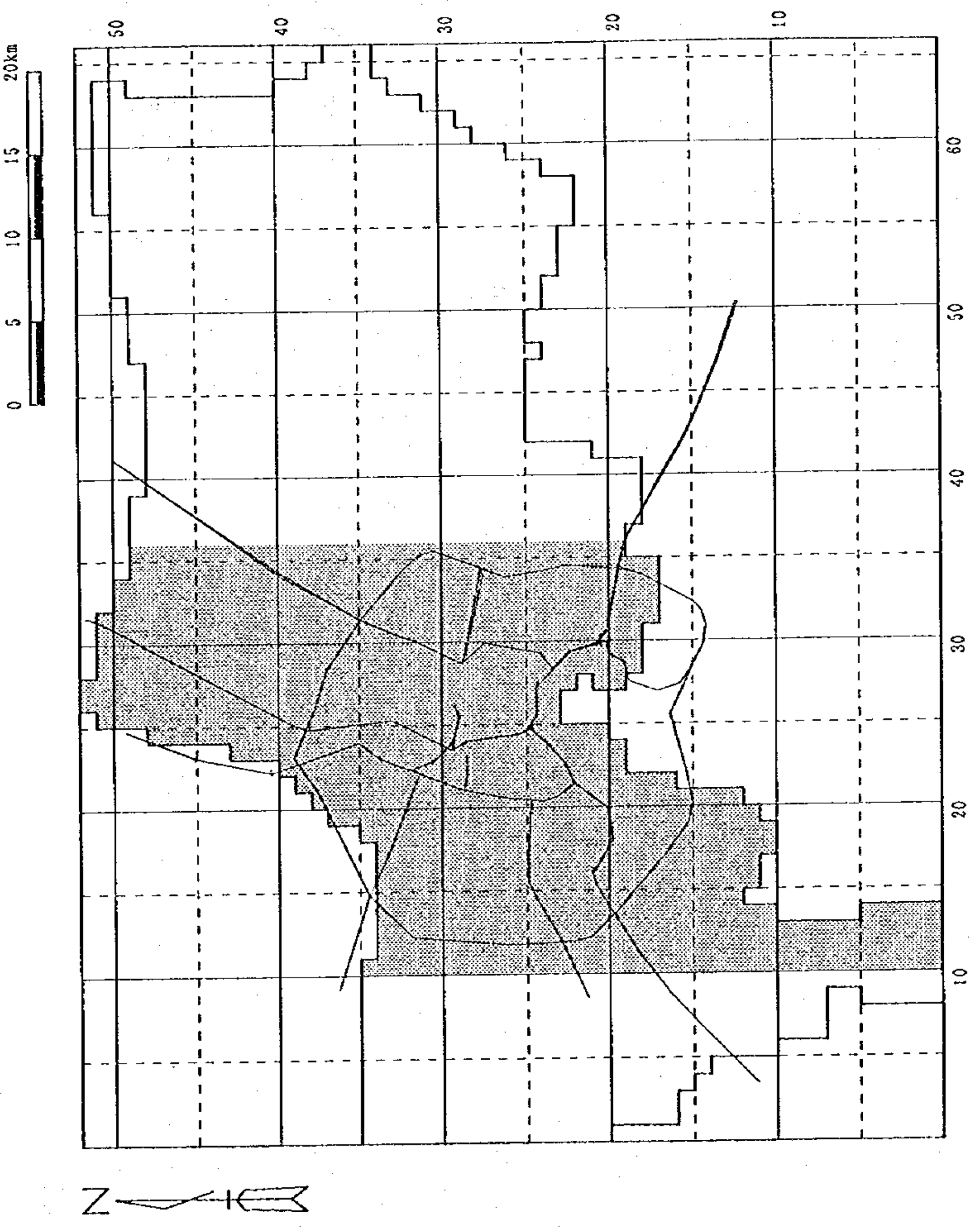



**Fig. AP-2.2 Simulation Area**

Note: Hatched area means the area of 500 m grid cells.
Other enclosed area means the area of 1 km grid cells.

### 3.6 Season and Time Zoning

Season was defined in order to consider the seasonal variation of effectual factors for diffusion, e.g., primary wind direction. One (1) year is divided into three (3) seasons as same as season definition of JICA, 1991.

There is also daily variation of effective factors, e.g., solar and net radiation, traffic volume variation. To take them into account, One (1) year is divided into four (4) time zones by the variation of traffic volume and the concentration variation of air pollutant (Fig. AP-2.3 and Fig. AP-2.4).

The zonings are shown in Table AP-2.1.

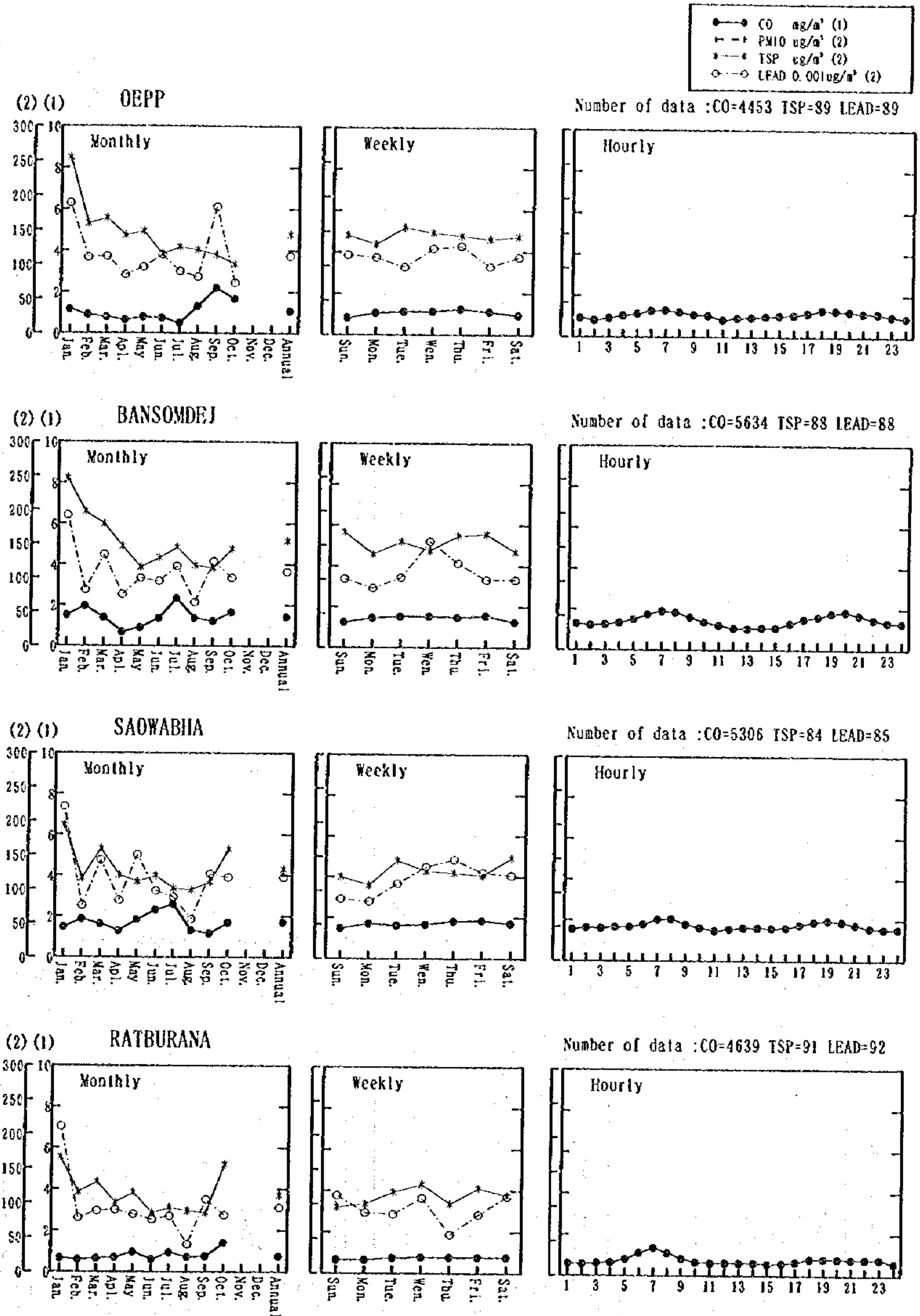
**Table AP-2.1 Season Zoning and Time Zoning**

| Season | Month |
|---|---|
| Wet Season | May to October |
| Dry Season | November to January |
| Intermediate | February to April |

Source: BEIP Study Team

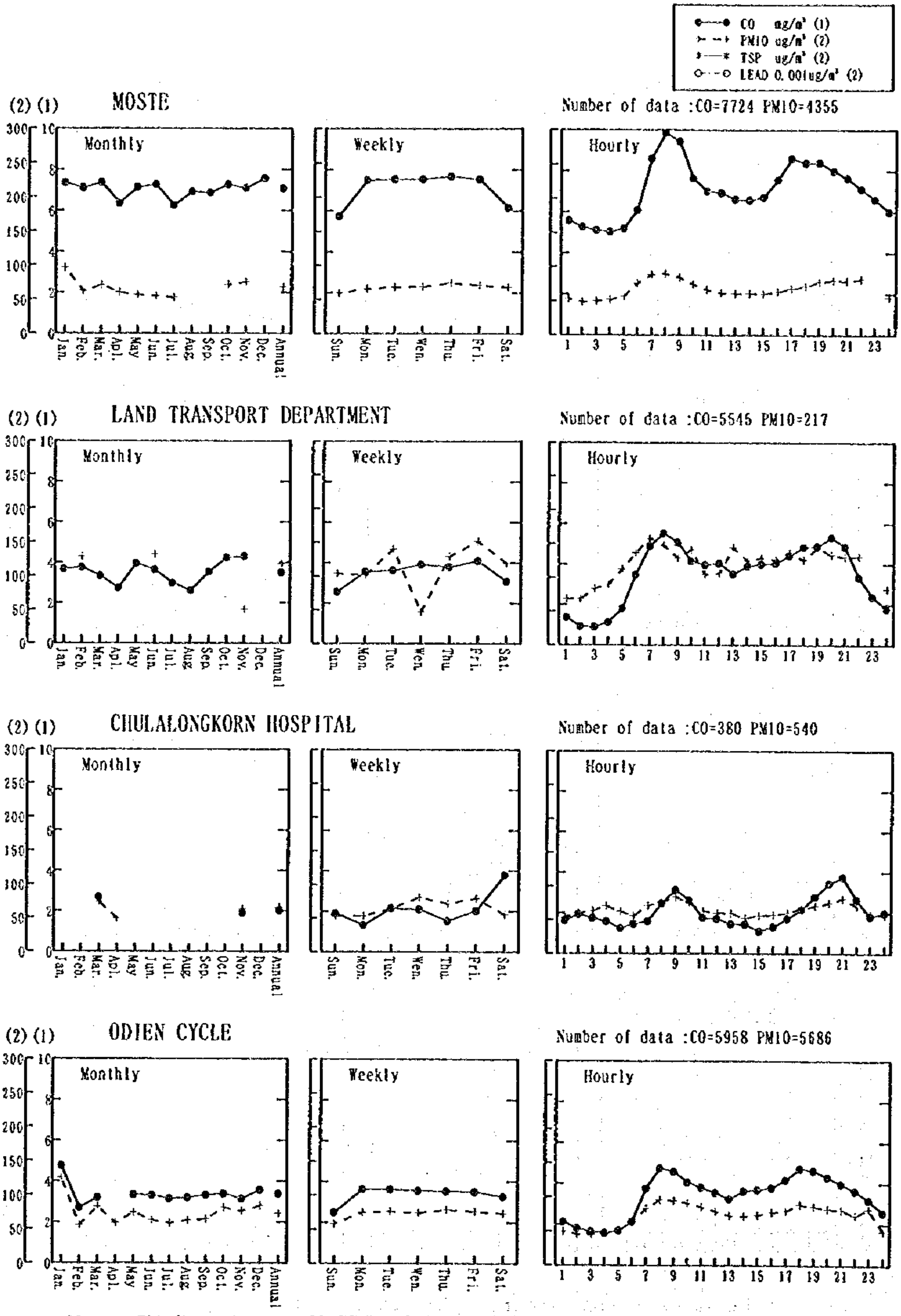
| Time zone | Time |
|---|---|
| Morning | 6:01 ~ 10:00 |
| Afternoon | 10:01 ~ 16:00 |
| Night | 16:01 ~ 23:00 |
| Midnight | 23:01 ~ 6:00 |

Source: BEIP Study Team




Note: This diagram is processed by BEIP Study Team with the PCD's hourly/daily monitoring data
TSP and LEAD are originally daily data

**Fig. AP-2.3 Variations of Air Quality Concentration, 1994 (2537), General Stations**




Note: This diagram is processed by BEIP Study Team with the PCD's hourly/daily monitoring data

**Fig. AP-2.4 Variations of Air Quality Concentration, 1994 (2537), Roadside Stations**

## 4. Meteorological Modeling

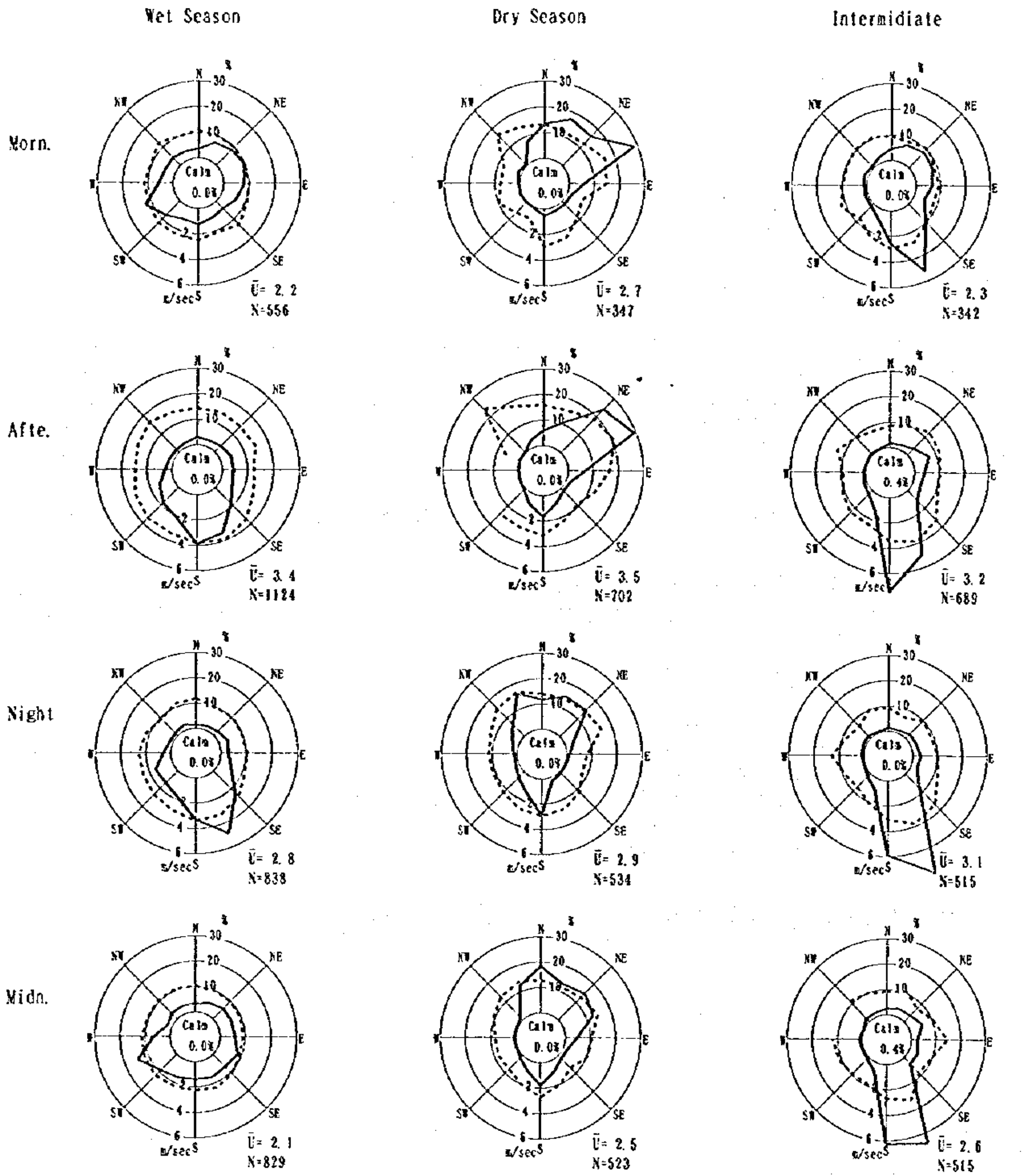
### 4.1 Applied Meteorological Data

Meteorological difference effective for dispersion is only a little in whole area of BMR because the topographic characteristic in BMR is very flat, although there is small scale difference induced by buildings. So, meteorological characteristic of BMR is modeled as uniform. An air pollution study whose target was Samut Prakan Province (JICA, 1991) supported this idea by data of 3 meteorological stations, as follows; "it is understood that meteorological conditions in the target area are nearly uniform."

Data of (MS1) ONEB Station, measured in 1988 by JICA, was applied for the simulation model. The reasons are as follows;

- The meteorological data of Meteorological Station in Bang Na has certain errors under weak wind condition (wind speed from 0 to 2 knots), which cause certain error in simulation.
- The meteorological data at PCD's monitoring stations have not reached 1 year round yet.
- The meteorological data at DPH's monitoring station have error that the frequency of north wind is 0%, although the other stations described above show that the frequency of north wind is 5 to 10 %.
- (MS1) ONEB Station does not have problems such as described above. Although it is 7-year-old data, change of natural condition is very slow so that the differences between 1995 and 1988 would be very little.

The Wind Rose Diagram at (MS1) ONEB Station is shown in Fig. AP-2.5.




(MS1) ONEB Station

——— Frequency of Wind Direction
······ Average of Wind Speed
Calm means less than 0.5 m/sec
Ū= means ave. of wind speed (m/sec)
N= means number of sample

Note: This diagram is processed by BEIP Study Team with the hourly/daily monitoring data of JICA, 1991

**Fig. AP-2.5 Wind Rose Diagrams of Applied Meteorological Data**

### 4.2 Atmospheric Stability

Pasquill's Stability Classification is generally prevalent to evaluate the atmospheric stability. Pasquill's Stability Classification redefined by Gen-an-kyo, 1982, as shown in Boxed Item, is adopted in this BEIP study because the available data were solar radiation, net radiation and wind speed.

Appearance frequency of atmospheric stability at (MS1) ONEB Station is shown in Fig. AP-2.6.

*Boxed Item: Definitions of Pasquill's Stability Classification*

**1. Pasquill's Stability Classification (Original)**

Atmospheric stability was originally classified by the vertical profile of atmospheric temperature. However, it is difficult to make continuous measurements (up to an altitude of 1000 m above the ground) of the vertical distribution of atmospheric temperature. Also, smoke plume diffusion is greatly influenced not only by the vertical distribution of atmospheric temperature, but also by wind velocity, and is related to other factors as well. Therefore, Pasquill proposed a method of classifying the atmospheric stability into A through F, from simple meteorological observations, with respect to wind velocity, solar radiation and cloud amount, and this method had been adopted by the Meteorological Agency of England. Pasquill's stability classification is shown in Table 1.

**Table 1 Pasquill's Stability Classification, Pasquill, 1961**

| Surface wind Speed (m/sec) | Daytime Insolation | | | Nighttime | |
|---|---|---|---|---|---|
| | Strong | Moderate | Slight | Thinly overcast or >=4/8 cloudiness | <= 3/8 cloudiness |
| <2 | A | A-B | B | - | - |
| 2-3 | A-B | B | C | E | F |
| 3-5 | B | B-C | C | D | E |
| 5-6 | C | C-D | D | D | D |
| >6 | C | D | D | D | D |

Note: Strong insolation corresponds to sunny midday in midsummer in England, slight insolation to similar conditions in midwinter. Night refers to the period from 1 hour before sunset to 1 hour after dawn. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night, and for any sky conditions during the hour preceding or following night as defined above.

Source: Pasquill, 1961

Gifford added the G rank for blank area of the original Pasquill's classification.

**2. Types of Redefined Pasquill's Stability Classification**

Solar radiation was not given quantitatively and nighttime classifications were dependent on the cloud volume in these classifications. But due to the progress of the measuring instrument, solar radiation and net radiation flux are easily obtainable, and Pasquill's stability classifications are redefined with available data. Many classifications have been proposed.

Three major classifications are mainly used nowadays, depending on the available data, shown in Table 2. The data made by three methods should not be equal because the using data are different. So, the Pasquill's classification data should be treated with the method information.

**Table 2 Major Pasquill's classifications in related with the data**

| Method | Table | Day time | | Night time | |
|---|---|---|---|---|---|
| | | Solar radiation | Net radiation | Cloudiness | Net radiation |
| JEA, 1993 | 3 | O | - | O | - |
| Senshu, 1977 | 5 | - | O | - | O |
| Gen-an-kyo, 1982 | 6 | O | - | - | O |

Source: JEA, 1993 and JEA, 1982

## 3. Redefined Pasquill's Stability Classification (JEA, 1993)

Table 3 shows the Pasquill's stability classifications of JEA, 1993, which is used when solar radiation and decimal cloudiness data are available. This classification can be used for the Meteorological Station's data in Bangkok.

**Table 3 Pasquill's Stability Classification, JEA, 1993**

| Surface wind Speed (m/sec) | Daytime | | | | Nighttime | | |
|---|---|---|---|---|---|---|---|
| | Solar radiation (T, kW/m²) | | | | Cloudiness (0 ~ 10) | | |
| | T >=0.60 | 0.60>T >=0.30 | 0.30>T >=0.15 | 0.15>T | 8 ~ 10 | 5 ~ 7 | 0-4 |
| U<2 | A | A-B | B | dD | nD | G | G |
| 2<=U<3 | A-B | B | C | dD | nD | E | F |
| 3<=U<4 | B | B-C | C | dD | nD | nD | E |
| 4<=U<6 | C | C-D | dD | dD | nD | nD | E |
| 6<=U | C | dD | dD | dD | nD | nD | E |

Note: Daytime means the time when the solar radiation is plus. The fist and the last hour of the Nighttime are defined as D, even if the cloudiness is less than 8/10.

Source: JEA, 1993 and JEA, 1982

## 4. Redefined Pasquill's Stability Classification (Senshu, 1977)

Table 4 shows the Pasquill's stability classifications of Senshu, 1977, which is used when net radiation data is available and solar radiation data is not available. This classification can be applied for the PCD's Rangsit Station data.

**Table 4 Pasquill's Stability Classification, Senshu, 1977**

| Surface wind Speed (m/sec) | Daytime: Net radiation (γ, cal/cm²/h) γ >=30 | 30>γ >=15 | 15>γ >=7.5 | 7.5>γ >=0 | Nighttime: 0>γ >=-1.8 | -1.8>γ >=-3.6 | -3.6>γ |
|---|---|---|---|---|---|---|---|
| U<2 | A | A-B | B | dD | nD | G | G |
| 2<=U<3 | A-B | B | C | dD | nD | E | F |
| 3<=U<4 | B | B-C | C | dD | nD | nD | E |
| 4<=U<6 | C | C-D | dD | dD | nD | nD | E |
| 6<=U | C | dD | dD | dD | nD | nD | E |

Source: JEA, 1982

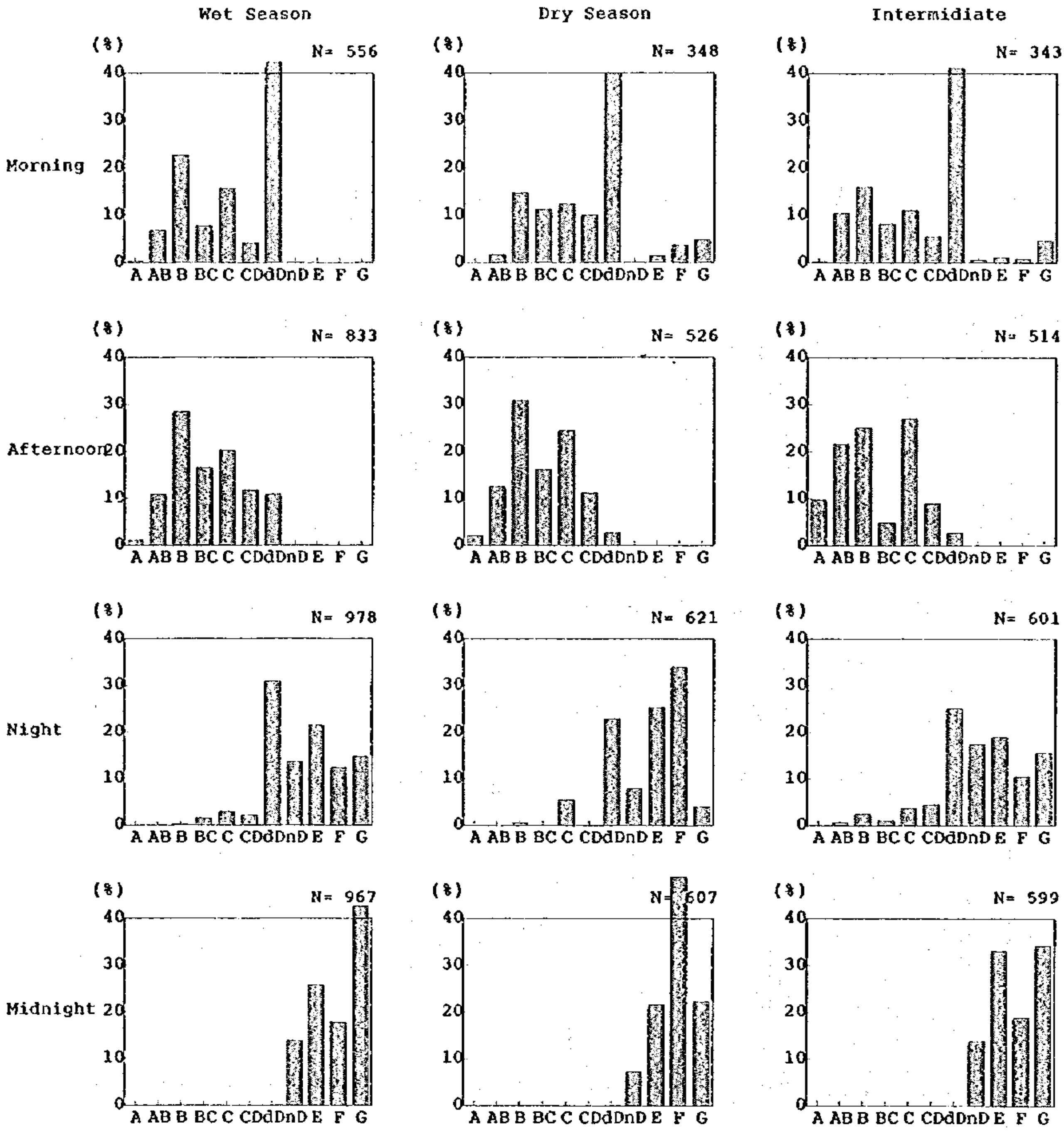
## 5. Redefined Pasquill's Stability Classification (Gen-an-kyo, 1982)

Table 5 shows the Pasquill's stability classifications of Gen-an-kyo, 1982, which is used when both of solar and net radiation data are available. This classification was applied for the (MS1) ONEB Station in this BEIP Study.

**Table 5 Pasquill's Stability Classification, Gen-an-kyo, 1982**

| Surface wind Speed (m/sec) | Daytime: Solar radiation (T) (kW/m²) T >=0.60 | 0.60>T >=0.30 | 0.30>T >=0.15 | 0.15>T | Nighttime: Net radiation (Q) (kW/m²) Q >=-0.020 | -0.020>Q >=-0.040 | -0.040>Q |
|---|---|---|---|---|---|---|---|
| U<2 | A | A-B | B | dD | nD | G | G |
| 2<=U<3 | A-B | B | C | dD | nD | E | F |
| 3<=U<4 | B | B-C | C | dD | nD | nD | E |
| 4<=U<6 | C | C-D | dD | dD | nD | nD | E |
| 6<=U | C | dD | dD | dD | nD | nD | E |

Source: JEA, 1993




(MS1) ONEB Station

Stablity : Pasquill Classification
Modified by GEN-AN-KYO ( 1982 )

N= means number of sample

Note: This diagram is processed by BEIP Study Team with the hourly/daily monitoring data of JICA, 1991

**Fig. AP-2.6 Frequency of Atmospheric Stability of Applied Meteorological Data**

## 4.3 Vertical Zoning and Estimation of Upper Layer Wind

Generally, the wind speed tends to increase with height from the ground surface. The diffusion field was divided into three fields in the vertical direction as shown in Table AP-2.2.

**Table AP-2.2 Vertical Zoning**

| | Diffusion Zone | Type of Source | Height of Source | Representative Height of Diffusion Field |
|---|---|---|---|---|
| 1 | Surface | Vehicle | 5 ~ 15m | 3m |
| 2 | Lower | Household | 30m | 30m |
| 3 | Upper | Power Plants | 70 ~ 110m | 100m |

Source: BEIP Study Team

The data at (MS1) ONEB were observed at 30m high and directly used for the simulation of air pollutants from household. Equation of G. A. De Marais, 1959, was applied to estimate the wind speed of other fields. The equation is;

$$U_z = U_s\left(\frac{Z}{Zs}\right)^p$$

where;

Uz: Estimated wind speed at height Z(m)
Us: Measured wind speed at height Zs(m)
p: Factor, as shown in Table AP-2.3.

**Table AP-2.3 Factor p**

| Stability | A | AB-B | BC-C | CD-D | E | F & G |
|---|---|---|---|---|---|---|
| P | 0.1 | 0.15 | 0.2 | 0.25 | 0.25 | 0.3 |

Source: G. A. De Marais, 1959

## 4.4 Meteorological Classification

The original classification of wind direction (16 direction and calm) and atmospheric stability (11 rank, A to G) was also utilized for simulation modeling.

Wind speed data were classified as Table AP-2.4 and the average speed of each rank is used as representative wind speed.

**Table AP-2.4 Wind Speed Classification**

| Rank | Wind Velocity | | | Representative Wind Velocity |
|---|---|---|---|---|
| Calm | 0.0 | ~ | 0.4m/s | - |
| Windy-1 | 0.5 | ~ | 0.9m/s | Yearly Average of each Rank |
| Windy-2 | 1.0 | ~ | 1.9m/s | |
| Windy-3 | 2.0 | ~ | 2.9m/s | |
| Windy-4 | 3.0 | ~ | 3.9m/s | |
| Windy-5 | 4.0 | ~ | 5.9m/s | |
| Windy-6 | 6.0 | ~ | 7.9m/s | |
| Windy-7 | 8.0m/s~ | | | |

Source: BEIP Study Team

## 5. Source Modeling

### 5.1 Source Type

Sources with quantitative air pollutants were modeled as point or line source individually. Sources with small pollutants were compiled to area sources. The definition of modeling is shown in Table AP-2.5.

**Table AP-2.5 Source Type**

| Source | | Type |
|---|---|---|
| • Vehicle | • Freeway<br>• Fly over<br>• Other major road from which SPM is emitted more than or equal 10 kg/km/h (cases using emission factor for 1992) or 2 kg/km/h (cases using emission factor for future) | Line |
| | • Other minor road | Area |
| • Thermal Power Plant | | Point |
| • Household | | Area |

Source: BEIP Study Team

### 5.2 Variation of Emission

The daily and seasonally variation of emission amount from each source are estimated as follows;

- Vehicle: The daily variation of traffic volume and travel speed was taken into account. These variation data are output of the transport analysis of this BEIP Study Team;
- Thermal Power Plant: It is assumed that emission volume is constant; and
- Household: Fuel consumption ratio by time zone was summarized by the field survey as shown in Table AP-2.6.

**Table AP-2.6 LPG Consumption Ratio of Household**

| Time Zone | Morning | Afternoon | Night | Midnight |
|---|---|---|---|---|
| Ratio | 0.366 | 0.066 | 0.568 | 0.000 |

Source: Questionnaire survey of fuel consumption, BEIP Study Team

## 6. Diffusional Modeling

### 6.1 Effective Stack Height

Effective Stack Height was set or calculated as shown in Table AP-2.7.

**Table AP-2.7 Effective Stack Height**

| Source | Source Type | Windy | Calm |
|---|---|---|---|
| Vehicle | Expressway | 15m | 20m |
| | Flyover | 10m | 15m |
| | Others | 5m | 10m |
| Households | | 20m | 20m |
| Power Plants | | CONCAWE | Briggs |

Source: BEIP Study Team

The CONCAWE equation (CONCAWE, 1966) is

$$H_e = H_0 + 0.175 \cdot Q_H^{\frac{1}{2}} \cdot u^{-\frac{3}{4}}$$

where;

He: Effective stack height (m)
$H_0$: Actual stack height (m)
$Q_H$: Released heat (cal/s)

$$Q_H = \rho \cdot C_p \cdot Q \cdot (T_G - T_A)$$

where;

ρ: Air density at 0°C (1.293 x $10^3$ g/m$^3$)
$C_p$: Isopiestic specific heat (0.24 cal/K/g)
Q: Volume of emitted gas (m$^3$N/s)
$T_G$: Temperature of exhaust gas (°C)
$T_A$: Temperature of atmosphere (28 °C)
u: Wind speed at stack top (m/s)

The Briggs equation (Briggs, 1969) is

$$H_e = H_0 + 1.4 \cdot Q_H^{1/4} \cdot (d\theta / dz)^{-3/8}$$

where;

dθ/dz: Temperature gradient (Daytime: 0.005 °C/m, Nighttime: 0.010 °C/m)

Stack information for calculation of effective height of the thermal power plants are shown in Table AP-2.8.

**Table AP-2.8 Stack Information of the Thermal Power Plants**

| Stack | | Stack Height (m) | Temperature (C°) | Exhaust gas ($10^3 m^3N/h$) |
|---|---|---|---|---|
| South Bangkok P.P. | 1 | 76 | 140.0 | 493 |
| | 2 | 76 | 140.0 | 493 |
| | 3 | 84 | 135.0 | 740 |
| | 4 | 110 | 135.0 | 740 |
| | 5 | 110 | 150.0 | 740 |
| North Bangkok P.P. | 1 | 70 | 140.0 | 207 |
| | 2 | 70 | 140.0 | 207 |
| | 3 | 70 | 140.0 | 241 |

Source: JICA, 1991 (Stack Height and Temperature of South Bangkok P. P)
Estimated by BEIP Study Team (Stack Height and Temperature of North Bangkok P. P.)
PCD, 1994 (Fuel Consumption)
Exhaust gas volume was estimated as
$V = W \times K / 8760$
where;
V: Exhaust gas volume ($m^3N/h$)
W: Fuel Consumption (ton/y)
K: Exhaust gas factor for heavy fuel oil (12,000$m^3N$/ton)

## 6.2 Diffusion Formulas

Gaussian plume model equation and gaussian puff model equation are selected for diffusion formulas, as shown in Table AP-2.9.

**Table AP-2.9 Diffusion Formulas**

| Source | Windy | Calm |
|---|---|---|
| Point | Simplified Gaussian Plume Equation | Simplified Gaussian Puff Equation |
| Line | Simplified Gaussian Plume Equation | Simplified Gaussian Puff Equation |
| Area | Simplified Gaussian Plume Equation | Simplified Gaussian Puff Equation |

Source: BEIP Study Team

### (1) Gaussian Plume Equation

Original formula of gaussian plume model is as follows:

$$C(x,y,z) = \frac{Q_P}{2\pi\sigma_y\sigma_z u}\cdot\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\cdot F$$

where;

$$F = \left\{\exp\left[-\frac{(z-He)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+He)^2}{2\sigma_z^2}\right]\right\}$$

C: Concentration at calculation point.
x: Distance from source to calculation point along wind direction (m).
y: Distance from source to calculation point upright to wind direction (m).
z: Height of calculation point (m).

Qp: Emission rate of pollutant ($m^3N/sec$).
u: Wind speed (m/sec).
He: Effective stack height
$\sigma_y$: Diffusion width upright to wind direction (m)
$\sigma_z$: Vertical diffusion width (m)

Because the original formula is time consuming in the practical use, this formula was simplified by Holland 1953 with the assumption that frequency inside each 16 wind direction rank is constant, which is applied for the BEIP simulation model.

$$C(R,z)=\sqrt{\frac{1}{2\pi}}\frac{Q_p}{\frac{\pi}{8}R\sigma_z u}\cdot F$$

where;

R: Distance from source to calculation point (m)

### (2) Gaussian Puff Equation

On the other hand, Formula of original gaussian puff model is as follows:

$$C(x,y,z)=\frac{Q_p}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\cdot\exp\left(-\frac{(x-ut)^2}{2\sigma_x^{\ 2}}-\frac{y^2}{2\sigma_y^{\ 2}}\right)\cdot F$$

where;

t: Time from stack or exhaust gas pipe (sec)
Others: same as the Plume Equation Section

It is also time consuming in the practical use and simplified equation, which was used in BEIP simulation model, is as follows;

$$C(R,z)=\frac{Q_p}{(2\pi)^{3/2}\gamma}\cdot\left\{\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(He-z)^2}+\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(He+z)^2}\right\}$$

where;

$\alpha=\sigma_x/t=\sigma_y/t$ (t: 3600 sec)
$\gamma=\sigma_z/t$ (t: 3600 sec)

## 6.3 Diffusion Width

### (1) Diffusion Width for Plume Equation

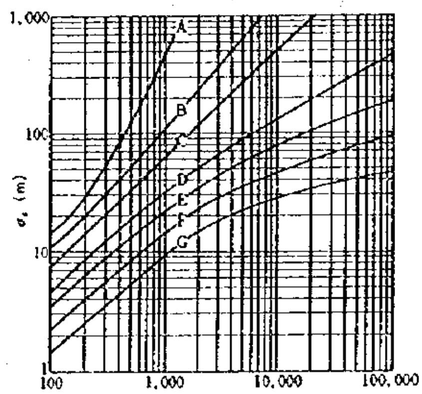
JEA Equation which simulating Pasquill - Gifford Chart (Fig. AP-2.7) was used for plume equation. The equation is;

$$\sigma_z(x)=\gamma_z\cdot x^{\alpha_z}+\sigma_{z0}$$

where;

$\gamma_z$, $\alpha_z$: Constants depending atmospheric stability (Table AP-2.10).
x: Distance from source along wind direction (m).
$\sigma_{z0}$: Original Diffusion Width
Line source of vehicle: Road width for each direction (m)
Power Plant: 0m
Area sources: 5m

**Fig. AP-2.7 Pasquill - Gifford Chart**




Source: JEA, 1993

### (2) Diffusion Width for Puff Equation

JEA Table leaded from Turner Chart was used for puff equation (Table AP-2.11).

**Table AP-2.10 Constant for $\sigma_z$**

| Stability | $\alpha_z$ | $\gamma_z$ | x (m) |
|---|---|---|---|
| A | 1.122 | 0.0800 | 0 ~ 300 |
| | 1.514 | 0.00855 | 300 ~ 500 |
| | 2.109 | 0.000212 | 500 ~ |
| AB | 1.024 | 0.1100 | 0 ~ 300 |
| | 1.278 | 0.0259 | 300 ~ 500 |
| | 1.601 | 0.00347 | 500 ~ |
| B | 0.964 | 0.1272 | 0 ~ 500 |
| | 1.094 | 0.0570 | 500 ~ |
| BC | 0.949 | 0.1139 | 0 ~ 500 |
| | 1.000 | 0.0800 | 500 ~ |
| C | 0.918 | 0.1068 | 0 ~ |
| CCD | 0.872 | 0.1233 | 0 ~ |
| CD | 0.839 | 0.1262 | 0 ~ 2,000 |
| | 0.756 | 0.236 | 2,000 ~ 10,000 |
| | 0.816 | 0.1367 | 10,000 ~ |
| CDD | 0.808 | 0.1355 | 0 ~ 1,000 |
| | 0.737 | 0.222 | 1,000 ~ 4,000 |
| | 0.637 | 0.507 | 4,000 ~ |
| D | 0.826 | 0.1046 | 0 ~ 1,000 |
| | 0.632 | 0.400 | 1,000 ~ 10,000 |
| | 0.555 | 0.811 | 10,000 ~ |
| DE | 0.777 | 0.1118 | 0 ~ 2,000 |
| | 0.572 | 0.529 | 2,000 ~ 10,000 |
| | 0.499 | 1.038 | 10,000 ~ |
| E | 0.788 | 0.0928 | 0 ~ 1,000 |
| | 0.565 | 0.433 | 1,000 ~ 10,000 |
| | 0.415 | 1.732 | 10,000 ~ |
| EF | 0.791 | 0.0733 | 0 ~ 1,000 |
| | 0.547 | 0.395 | 1,000 ~ 10,000 |
| | 0.366 | 2.09 | 10,000 ~ |
| F | 0.784 | 0.0621 | 0 ~ 1,000 |
| | 0.526 | 0.370 | 1,000 ~ 10,000 |
| | 0.323 | 2.41 | 10,000 ~ |
| FG | 0.789 | 0.0481 | 0 ~ 1,000 |
| | 0.582 | 0.202 | 1,000 ~ 2,000 |
| | 0.479 | 0.442 | 2,000 ~ 10,000 |
| | 0.273 | 2.954 | 10,000 ~ |
| G | 0.794 | 0.0373 | 0 ~ 1,000 |
| | 0.637 | 0.1105 | 1,000 ~ 2,000 |
| | 0.431 | 0.529 | 2,000 ~ 10,000 |
| | 0.222 | 3.62 | 10,000 ~ |

Source: JEA, 1993

**Table AP-2.11 JEA Table for Puff Equation**

| Stability | $\alpha$ | $\gamma$ |
|---|---|---|
| A | 0.948 | 1.569 |
| AB | 0.859 | 0.862 |
| B | 0.781 | 0.474 |
| BC | 0.702 | 0.314 |
| C | 0.635 | 0.208 |
| CCD | 0.589 | 0.181 |
| CD | 0.542 | 0.153 |
| CDD | 0.506 | 0.133 |
| D | 0.470 | 0.113 |
| DE | 0.455 | 0.090 |
| E | 0.439 | 0.067 |
| EF | 0.439 | 0.058 |
| F | 0.439 | 0.048 |
| FG | 0.439 | 0.039 |
| G | 0.439 | 0.029 |

Source: JEA, 1993

### 6.4 Atmospheric Stability and Stability for Diffusion Width

Table AP-2.12 is showing the relationship setting in the BEIP Simulation Model, between Pasquill's Atmospheric Stability Classification and the stability for Diffusion Width table.

**Table AP-2.12 Relationship between Atmospheric Stability and Stability for Diffusion Width**

| Season | Time Zone | Source | A ~ B | BC ~C | CD ~dD | nD | E ~ G |
|---|---|---|---|---|---|---|---|
| Wet Season May ~ Oct. | Morning | Surface & Lower | A | A | B | C | CD |
| | | Upper | BC | CD | CD | D | D |
| | Afternoon | Surface & Lower | A | A | B | C | CD |
| | | Upper | BC | CD | CD | CD | D |
| | Night | Surface & Lower | A | B | BC | C | CD |
| | | Upper | BC | CD | CD | CD | D |
| | Midnight | Surface & Lower | B | C | CD | D | E |
| | | Upper | BC | CD | CD | D | E |
| Dry Season Nov. ~ Jan. | Morning | Surface & Lower | A | B | C | CD | CD |
| | | Upper | BC | CD | CD | D | D |
| | Afternoon | Surface & Lower | A | B | BC | C | D |
| | | Upper | BC | CD | CD | CD | D |
| | Night | Surface & Lower | A | B | C | CD | CD |
| | | Upper | BC | CD | CD | CD | D |
| | Midnight | Surface & Lower | B | C | CD | D | E |
| | | Upper | BC | CD | CD | D | E |
| Intermediate Feb. ~ Apr.. | Morning | Surface & Lower | A | B | C | CD | CD |
| | | Upper | BC | CD | CD | D | D |
| | Afternoon | Surface & Lower | A | B | BC | C | CD |
| | | Upper | B | C | CD | CD | D |
| | Night | Surface & Lower | A | B | C | CD | CD |
| | | Upper | BC | CD | CD | D | D |
| | Midnight | Surface & Lower | B | C | CD | D | E |
| | | Upper | BC | CD | CD | D | E |

Source: BEIP Study Team

### 6.5 Reaction Model from NOx to $NO_2$

Reaction Model from NOx to $NO_2$ follows the model of Yamamoto, Yokoyama, et al. (1978). The equation is;

$$[NO_2] = [NOx]_D \cdot \left[1 - \frac{\alpha}{1+\beta}\left\{\exp(-Kt) + \beta\right\}\right]$$

where;

$K = 0.208 \cdot u \cdot [O_3]_B \cdot k$ : Vehicle and Household

$K = 0.0062 \cdot u \cdot [O_3]_B \cdot k$ : Power Plants

$[NO_2]$, $[NOx]_D$: Concentration of $NO_2$ and NOx

α: Factor (=0.9)
β: Factor (=0.3)
u: Wind Speed (m/s)
t: Time from stack/ exhaust gas pipe (sec)
$[O_3]_B$: Back Ground Concentration of $O_3$, shown in Table AP-2.13
k: $O_3$ Back Ground Factor, shown in Table AP-2.13

**Table AP-2.13 Back Ground Concentration of $O_3$ (MS1: ONEB Station in 1988) and $O_3$ Back Ground Factor**

| Time Zone | Daytime | | Nighttime | |
|---|---|---|---|---|
| Stability | A ~ CD | D | D | E ~ G |
| $[O_3]_B$ | 0.014 | 0.010 | 0.005 | 0.005 |
| k (Parallel wind to line source) | 0.55 | 0.55 | 0.33 | 0.33 |
| k (other cases) | 1 | 1 | 1 | 1 |

Note: If the source is line source and the azimuth between the direction of line and the wind direction is less than or equal 30 degree, k is 0.55 at daytime and is 0.33 in nighttime. k is 1.0 in other cases.
Source: JICA, 1991

## 7. Reproducibility of the BEIP Simulation Model for Air Pollution

Reproducibility of the diffusion simulation model was checked through regression analysis using the actual monitored data of CO.

The Scatter Diagram of estimated and actual CO concentration (annual) is shown in Fig. AP-2.8. The model is considered to have sufficient reproducibility as the gradient of regression line is near to 1.0 and the coefficient of correlation is more than 0.9.

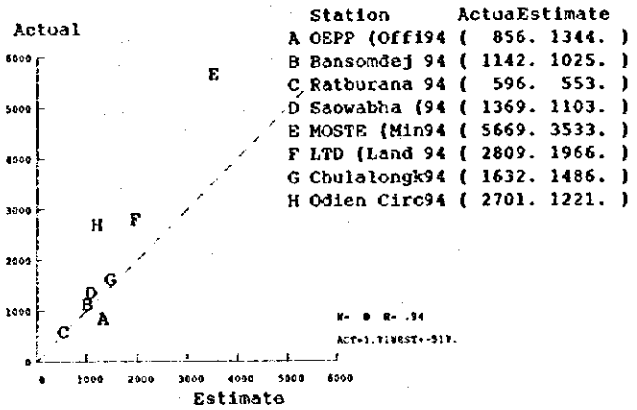



**Fig. AP-2.8 Scatter Diagram Comparing the Simulation Result (Estimate) and the Monitoring Result in 1994 (Actual) (CO, ppb)**

## 8. Comparison of Simulated Annual Average to Air Standards

There are various ambient air standards, that is 1 hour, 8 hours, 24 hours, monthly and geometric annual mean. To evaluate the simulated annual average concentration by these standard, ranking table compared to the ambient air standards were prepared, as shown in Table AP-2.14.

**Table AP-2.14 Ranking of Annual Arithmetic Average of Air Pollutant Concentration,**

| | PM-10 ($\mu g/m^3$) | CO (ppb) | $SO_2$ (ppb) | $NO_2$ (ppb) |
|---|---|---|---|---|
| Much Lower than the Standard | ≤ 20 | ≤ 722 | ≤ 9 | ≤ 9 |
| Lower than the Standard | ≤ 40 | ≤ 1445 | ≤ 19 | ≤ 17 |
| Possibly Lower than the Standard | ≤ 52 | ≤ 2131 | ≤ 24 | ≤ 21 |
| Possibly Higher than the Standard | ≤ 88 | ≤ 4748 | ≤ 36 | ≤ 30 |
| Higher than the Standard | ≤ 177 | ≤ 9496 | ≤ 72 | ≤ 60 |
| Extremely Higher than the Standard | 177< | 9496< | 72< | 60< |

Source: BEIP Study Team

Fig. AP-2.9 shows the flow chart of the process to define the ranking.

First, maximum of 1 hour data, maximum of 8 hours, 24 hours and monthly average and geometric annual mean (hereinafter, refereed as Mi), and arithmetic mean (hereinafter, Ma) were calculated for each station. JICA's monitoring results in 1988 in Samut Prakan area were included to this process because the PCD's monitoring stations in 1994 din't have a station to monitor SO2 and NO2.

Second, the ratios (hereinafter, Ri) of Ma/Mi are calculated for each station.

Third, the standards are converted to equivalent annual means (hereinafter, Ei) by Ri and Ambient Air Standards (Si).

Forth, the most strict value among the standards were selected (hereinafter, Es), which are the lowest value of Ei.

Fifth, the most strict value among the stations (Es.min) is defined as the limit of "Lower than the Standard" and "Possibly Lower than the Standard," while the half of Es.min is the limit of "Lower than the Standard" and "Much Lower than the Standard."

The average of Es(j) is defined as the limit of "Possibly Lower than the Standard" and "Possibly Higher than the Standard."

The highest value of Es(j) (hereinafter, Es.max) is the limit of "Higher than the Standard" and "Possibly Higher than the Standard." Double of Es.max is the limit of "Higher than the Standard" and "Extremely Higher than the Standard."

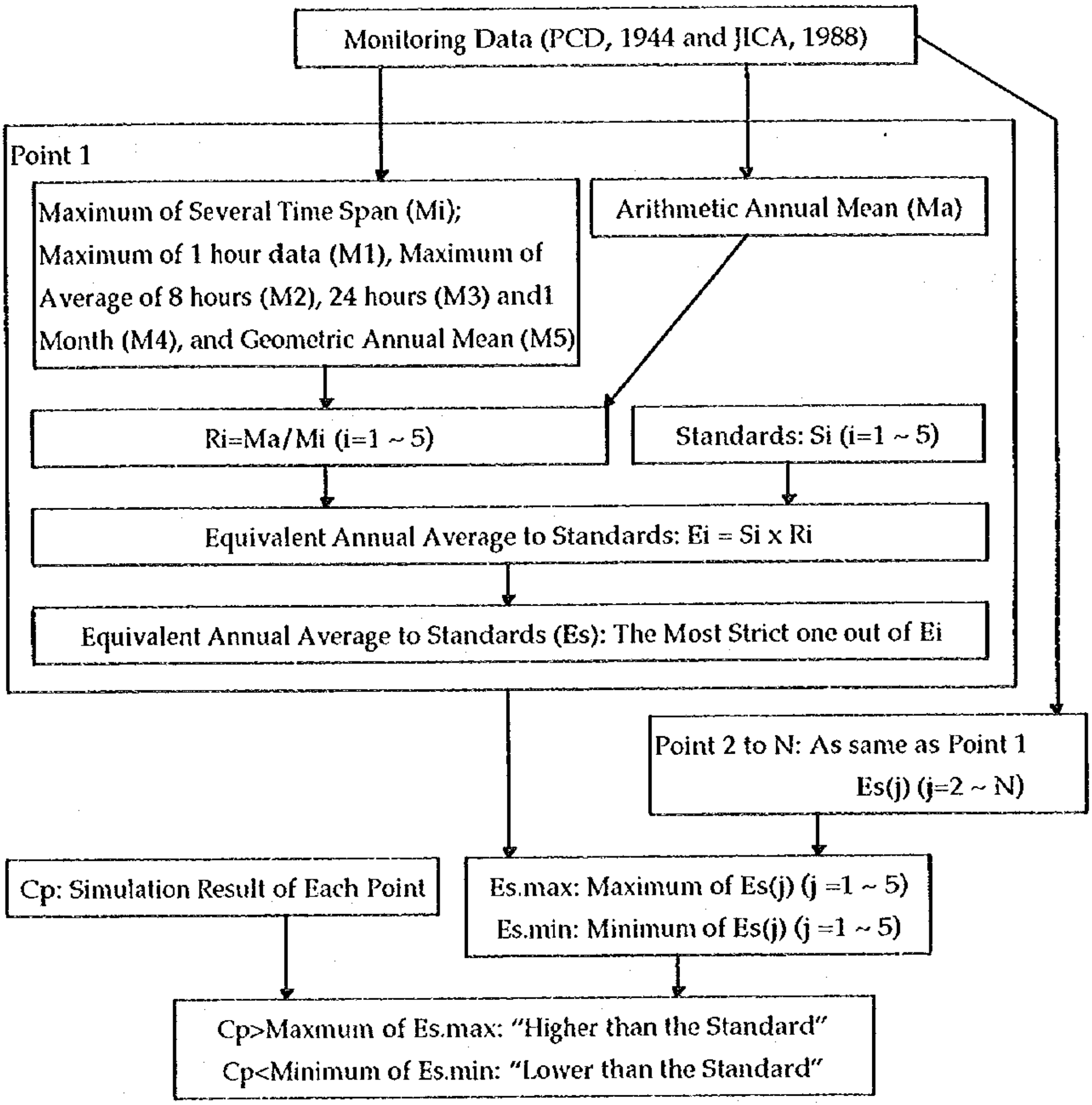



**Fig. AP-2.9 Flow Chart of Comparison of Simulated Annual Average to Air Standards**

## 9. Principal References

The Study on the Air Quality Management Planning for the Samut Prakarn Industrial District in the Kingdom o Thailand, JICA, 1991

NOx manual, JEA, 1993 (in Japanese)

Air Emission Database of Vehicles and Industry in Bangkok Metropolitan Region 1992, Final Report, PCD, 1994

JICA