- NOx Emission

$$N = 1.49 * P^{1.14} * (A_1^{1.14} * T_1 * d_1 + A_2^{1.14} * T_2 * d_2) / 1000 * 46/22.2$$

Where,

S : SO_X emission (kg/vessel)
s : Sulfur contents in fuel (weight %)
P : Rated power(PS/engine) (shown in Table 4.2.1.14)
W: Fuel Consumption(kg/vessel)
N : NOx emission (kg/vessel)
A_1 : Load factor at loading (shown in Table 4.2.1.17)
A_2 : Load factor at non-loading (shown in Table 4.2.1.17)
T_1 : Loading hours (= Mooring hours * Time ratio : shown in Table 4.2.1.17, 4.2.1.18)
T_2 : Non-loading hours (= Mooring hours *(1- Time ratio) : shown in Table 4.2.1.17, 4.2.1.18)
d_1 : Number of operating engines at loading (shown in Table 4.2.1.17)
d_2 : Number of operating engines at non-loading (shown in Table 4.2.1.17)

Emission for Main & Sub Boiler

- SOx Emission

$$S = W * s * 1/100 * 64/32$$

- NOx Emission

$$N = W * n$$

$$W = F * (A_1 * T_1 + A_2 * T_2)$$

Where,

n : NOx emission factor (kg/kg) (0.070kg/kg based on IPCC/OECD(1996))
F : Rated Fuel Consumption (kg/vessel/hr) (shown in Table 4.2.1.15)
A_1 : Load factor at loading (shown in Table 4.2.1.17)
A_2 : Load factor at non-loading (shown in Table 4.2.1.17)
T_1 : Loading hours (= Mooring hours * Time ratio : shown in Table 4.2.1.18)
T_2 : Non-loading hours (= Mooring hours *(1- Time ratio) : shown in Table 4.2.1.17, 4.2.1.18)

Note: Share of fuel (Fuel Oil (2) : 100% based on Interview of ship company)

Table 4.2.1.14 Rated Power of Main & Sub Diesel Engines

Ship Type	Rated Power(PS) of Main Diesel Engines	Rated Power(kW) of Sub Diesel Engines
Full Cellular Container	$1.9GRT^{0.97}$	$2 * 2.2GRT^{0.60}$
Liquid Bulk	$12GRT^{0.70}$	$2 * 10GRT^{0.37}$
Solid Bulk, Semi-Container, Ro-Ro, Conventional	$19GRT^{0.65}$	$2 * 7.7GRT^{0.40}$
Fishing Boat	$73GRT^{0.50}$	$3 * 13GRT^{0.43}$
Others, Express boat, Ferry boat, Long-tailed boat	$33GRT^{0.61}$	2 * 0.089GRT

Note: GRT: gross tonnage(See Table 4.2.1.16)
Ro-Ro : cargo ships for vehicles.
1kW = 1.88*PS : based on NOx Manual

Table 4.2.1.15 Rated Fuel Consumption of Main & Sub Boilers

Ship Type	Rated Consumption of Main Boiler(liter/hr)	Rated Consumption of Sub Boiler(liter/hr)
Liquid Bulk(>= 100,000GRT)	$6.7GRT^{0.58}$	-
Liquid Bulk (< 100,000GRT)	-	$0.29GRT^{0.88}$
Others (Except Liquid Bulk)	-	$0.27GRT^{0.67}$

Note: GRT: gross tonnage(See Table 4.2.1.16)

Table 4.2.1.16 GRT Average by Ship Type

Unit: calls of vessel/year

GRT			Liquid Bulk	Solid Bulk	Fully Cellular Container	Semi-Container	Ro-Ro	Conventional	Others
Min	Max	Average							
0	99	50	0	4	0	0	0	6	316
100	499	300	102	203	4	0	0	102	495
500	999	750	998	232	31	2	0	221	162
1,000	2,999	2,000	2,184	780	227	83	15	578	817
3,000	4,999	4,000	2,139	942	278	31	16	815	155
5,000	9,999	7,500	690	454	2,201	251	52	2,693	55
10,000	14,999	12,500	202	317	1,681	170	19	1,101	27
15,000	19,999	17,500	107	272	648	43	120	517	19
20,000	24,999	22,500	176	154	36	1	52	341	2
25,000	29,999	27,500	155	174	10	6	51	301	18
30,000	49,999	40,000	156	153	225	6	110	291	33
50,000	59,999	55,000	250	4	235	0	71	2	10
60,000	74,999	67,500	58	2	0	0	0	2	0
75,000	99,999	87,500	11	0	0	0	0	0	0
100,000	100,000	100,000	147	14	0	0	0	2	0
Total			7,375	3,705	5,576	593	506	6,972	2,109
GRT Average			9,600	9,100	13,200	9,200	27,100	10,900	2,900

Source: "Thailand Shipping Statistics 2000 Ship Movement Series"
(June 2001, Office of the Maritime Promotion Commission, Ministry of Transport and Communications)

Table 4.2.1.17 Loading Patterns of Engines in Port Area

Ship Type	Non loading / Cruising in Port Area		Loading		Time Ratio
	Load of Sub Diesel	Load of Sub Boiler	Load of Sub Diesel	Load of Sub Boiler	Loading & Mooring
Full Cellular Container	0.42(1)	0.48(all)	-	-	0
Liquid Bulk	0.37(1)	0.19(all)	0.45(1)	0.76(all)	Ocean: 0.23 Inner sea: 1
Solid Bulk, Semi-Container, Ro-Ro, Conventional	0.42(1)	0.48(all)	0.46(2)	0.56(all)	Ocean: 0.23 Inner sea: 1
Others, Express boat, Ferry boat, Long-tailed boat	0.42(1)	0.48(all)	0.46(2)	0.56(all)	

Note: ( ) :number of operating engines
Ro-Ro : cargo ship for vehicles.

Table 4.2.1.18 Mooring Hours by Ship Type in Port Area

Unit:hours

GRT		Liquid Bulk	Solid Bulk	Fully Cellular Container	Semi-Container	Ro-Ro	Conventional	Others
Min	Max							
0	500	12	12	12	12	24	12	12
500	3,000	12	16	12	16	24	16	12
3,000	6,000	12	16	12	16	34	16	12
6,000	10,000	20	20	16	20	36	20	12
10,000	100,000	24	40	16	40	36	40	12

Table 4.2.1.19 Sulfur Contents in Fuel and Specific Gravity

Type of Fuel	Type of fuel	Sulfur Contents (wt%)	Specific gravity
Diesel	High Speed	0.0348	0.8358
Fuel Oil	No.1	1.7	0.9402
	No.2	1.7	0.9487

Source: Sulfur Contents of High Speed Diesel : Data from each refinery in Thailand, 2000
Sulfur Contents of Fuel Oil and Specific gravity of both fuel : DCR,2000

(2) Vessels on arrival and departure at ports

Emission for Main Diesel Engines

- SOx Emission

$S = W * s * 1/100 * 64/32$

$W = 0.21 * (P*A)^{0.95} * T$

- NOx Emission

$N = 1.49 * (P * A)^{1.14} * T / 1000 * 46/22.4 * 46/22.2$

Where,

P : Rated power(PS/engine) (shown in Table 4.2.1.14)

A: Load factor (shown in Table 4.2.1.20)

T : Cruising hours (Calculated based on the distance from the mooring site to the main cruising route and velocity shown in Table 4.2.1.20)

Table 4.2.1.20 Mode, Load Factor of Main Diesel and Vessel Velocity in Cruising

Extent	Mode	Load Factor of Main Diesel	Velocity
1.6km around the mooring site	Slow	0.17	5 knot
From 4.8km to 1.6km around the mooring site	Half	0.32	10 knot
From the mouse of river to 4.8km around the mooring site in Chaopraya River	Half	0.32	10 knot

Emission for Sub Diesel Engines

- SOx Emission

$S = W * s * 1/100 * 64/32$

$W = 0.17 *(P * A)^{0.98} * T * d$

- NOx Emission

$N = 1.49 *(P* A)^{1.14} * T * d / 1000 * 46/22.4$

Where,

A : Load factor at cruising in the Port area (shown in Table 4.2.1.17)

d : Number of operating engines (shown in Table 4.2.1.17)

Emission for Main & Sub Boiler

- SOx Emission

$S = W * s * 1/100 * 64/32$

- NOx Emission

$N = W * n$

$W = F * A* T$

Where,

F : Rated Fuel Consumption (kg/vessel/hr) (shown in Table 4.2.1.15)

A : Load factor at cruising in the Port area (shown in Table 4.2.1.17)

Note: Share of fuel (Fuel Oil (2) :100 %)

(3) Fishing Boats

- SOx Emission

$S = W * s * 1/100 * 64/32$

$W = 0.21 * (P*A)^{0.95} * T$

- NOx Emission

$N = 1.49 *(P* A)^{1.14} * T / 1000 * 46/22.4$

Where,

P : Rated power(PS/engine) (shown in Chapter 4 of Supporting Report)

A: Load factor (Half Mode as average : 0.32 based on NOx manual)

T : Cruising hours (785 hours : 157 days/year based on " The 2000 Intercensal Survey of Marine Fishery" , 5 hours/day based on interview of Department of Fisheries)

Note: Share of fuel (High Speed Diesel : 100% based on interview of Department of Fisheries)

(4) Small Boats (Express Boats, Ferry Boats, Long-Tailed Boats)

Express boats and ferry boats

- SOx Emission

$S = W * s * 1/100 * 64/32$

$W = 0.21 * (P*A)^{0.95} * T$

- NOx Emission

$N = 1.49 * (P * A)^{1.14} * T/ 1000 *46/22.4$

Where,

P : Rated power(PS/engine) (based on interviews of express boat and ferry boat companies)

A: Load factor (Half Mode in port area: 0.32 based on NOx manual)

T : Cruising hours (based on interview of express boat and ferry boat companies)

Note: Share of fuel (Fuel Oil(1) :100% based on an interview with the Harbor Dept.)

Long-Tailed boats

- SOx Emission

$S = W * s * 1/100 * 64/32$

$W = 0.21 * (P*A)^{0.95} * T$

- NOx Emission

$N = 1.49 * (P * A)^{1.14} * T / 1000 * 46/22.4$

Where,

P : Rated power(PS/engine) (based on an interview with the boat company)

A: Load factor (Half Mode in port area: 0.32 based on NOx manual)

T : Cruising hours (based on an interview with the boat company)

Note: Share of fuel (High Speed Diesel :100% based on an interview with the Harbor Dept.)

4) Estimated Emission

The estimated fuel consumption and SOx emission of vessels, fishing boats and small boats for the year 2000 in the whole Thailand are shown in Table 4.2.1.21 - 4.2.1.24 and Figure 4.2.1.13.

The total fuel consumption of vessels, fishing boats and small boats is about 210 kton/year in the year 2000. The total SOx emission is about 5,300 ton/year.

The fuel consumptions of ports in Bangkok, Chon Buri, Rayong accounts for about 35%, 25%, 20% of the total fuel consumption of vessels in the whole Thailand respectively. The share of Bangkok, Chon Buri, Rayong in the total SOx emission of vessels in the whole Thailand is the same as the share of the fuel consumption.

The SOx emissions of vessels and small boats account for 97% and 2% of the total SOx emission of ships in the whole Thailand respectively.

Table 4.2.1.21 Fuel Consumption of Vessels in the Year 2000

Unit: kton/year

Province	Liquid Bulk	Solid Bulk	Fully Cellular Container	Semi-Container	Ro-Ro	Conventional	Others	Total
Bangkok	8	4	19	2	1	18	1	53
Samut Sakhon	0	0				0	0	1
Chachoengsao	3	0	0	0		1	0	4
Chanthaburi							0	0
Chon Buri	10	3	5	1	3	17	0	39
Chumporn						0		0
Krabi	0	0			0	1	0	2
Nakhon Si Thammarat	1	0		0		1	0	2
Phetchaburi						0		0
Phuket	2	0	0		0	1	0	3
Prachuap Khiri Khan		0				2	0	2
Rayong	26	1	0	0	0	5	0	32
Satun						0	0	0
Songkhla	5	1	3	0	0	1	0	11
Surat Thani						0		0
Trang	0	1				0	1	2
Total	54	12	27	4	5	48	3	151

Table 4.2.1.22 SOx emission of Vessels in the Year 2000

Unit: ton/year

Province	Liquid Bulk	Solid Bulk	Fully Cellular Container	Semi-Container	Ro-Ro	Conventional	Others	Total
Bangkok	259	149	639	64	43	626	18	1,797
Samut Sakhon	3	8				5	9	25
Chachoengsao	86	0	1	0		39	3	129
Chanthaburi							0	0
Chon Buri	336	109	170	40	101	577	5	1,337
Chumporn						0		0
Krabi	1	14			4	46	3	69
Nakhon Si Thammarat	21	6		0		26	2	54
Phetchaburi						0		0
Phuket	67	3	3		13	22	9	117
Prachuap Khiri Khan		8				58	0	67
Rayong	886	40	6	6	2	156	1	1,096
Satun						4	3	7
Songkhla	167	47	89	12	6	45	6	374
Surat Thani						0		0
Trang	0	30				11	27	69
Total	1,825	414	908	122	168	1,616	87	5,141

Table 4.2.1.23 Fuel Consumption and SOx emission of Fishing Boats in the Year 2000

Province	Fuel Consumption (kton/y)	SOx Emission (ton/year)
Krabi	0.2	0.1
Chanthaburi	2.3	1.6
Chachoengsao	0.3	0.2
Chon Buri	2.1	1.4
Chumporn	4.0	2.8
Trang	2.0	1.4
Trat	5.0	3.5
Nakhon Si Thammarat	3.3	2.3
Narathiwat	0.1	0.1
Prachuap Khiri Khan	2.0	1.4
Pattani	2.5	1.7
Bangkok	0.0	0.0
Phangnga	0.8	0.5
Phetchaburi	2.6	1.8
Phuket	0.5	0.4
Ranong	0.9	0.6
Rayong	2.9	2.0
Songkhla	4.6	3.2
Satun	1.3	0.9
Samut Prakan	7.6	5.3
Samut Songkhram	4.2	2.9
Samut Sakhon	6.4	4.4
Surat Thani	2.4	1.6
Total	58	40

Table 4.2.1.24 Fuel Consumption and SOx emission of Small Boats in the Year 2000

Type of small boat	Fuel Consumption (kton/year)	SOx Emission (ton/year)
Express boat	1	36
Ferry boat	2	71
Long-tailed boat	2	2
Total	5	109

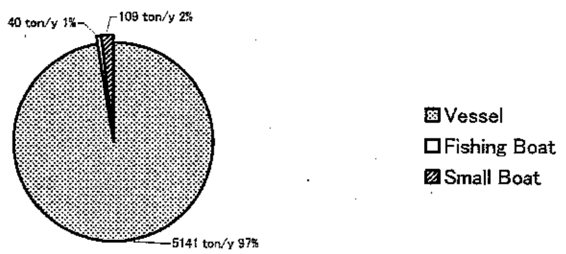


Figure 4.2.1.13 Share of SOx Emission of Ships in the whole Thailand in the Year 2000

4.2.1.4 Aircrafts

1) Outline

The flow of SOx emission estimation of aircraft for the year 2000 in the whole Thailand is shown in Figure 4.2.1.14.

The SOx emission of aircraft by airport is estimated using the number of flights for the year 2000 by aircraft type and the SOx emission factor in the LTO cycle based on the USEPA. The LTO cycle normally means the activity of approaching from the altitude of 1000m, landing, taxiing to the parking area, taxiing from the parking area, taking off and approaching to the altitude of 1000m. In this study, the LTO cycle, which includes from ground level to the altitude of 6000m, is applied considering the mixing heights : 6,000m adopted in the ATMOS2 model.

The fuel consumption is estimated using the actual sulfur contents of fuel and the estimated SOx emission.

The estimated fuel consumption of aircraft is compared with the statistics of the fuel consumption.

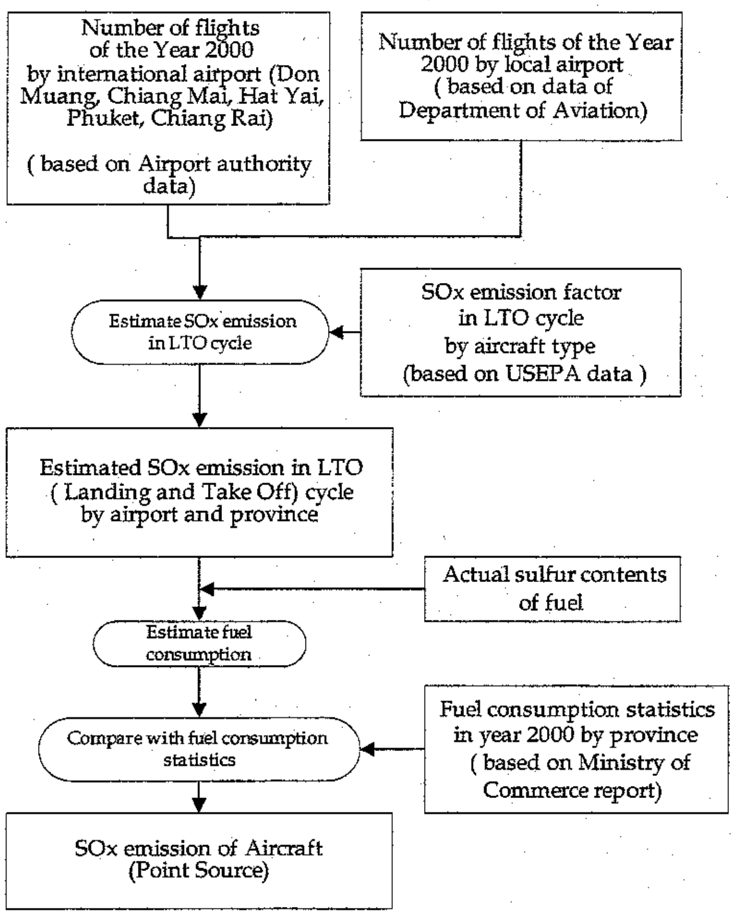


Figure 4.2.1.14 Flow of SOx emission estimation of aircraft for the Year 2000 in the whole Thailand

2) Traffic Data

The annual aircraft movement in the year 2000 is shown in Table 4.2.1.25, which is based on data of the Airport Authority and the Department of Aviation. The annual aircraft movement is about 310,000 flights/year in the year 2000. The annual aircraft movement in Bangkok International Airport accounts for more than 50% of the total annual aircraft movement in the whole Thailand.

The location of airports is shown in Figure 4.2.1.2.

Table 4.2.1.25 Annual Aircraft Movement in the Year 2000

Airport		Movement(Flight/year)
International airport	Bangkok	180,216
	Chiangmai	15,993
	Hatyai	10,940
	Phuket	23,322
	Chiang Rai	5,197
Local airport	Buri Ram	664
	Chumphon	446
	Hua Hin	16,255
	Khon Kaen	3,946
	Krabi	2,752
	Korat	1,702
	Lampang	1,885
	Mae Hong Son	2,764
	Mae Sot	1,082
	Nakhon Phanom	776
	Nakhon Si Thammarat	906
	Nan	1,354
	Narathiwat	1,661
	Pattani	24
	Phechabun	516
	Phitsanulok	7,018
	Pharae	1,842
	Ranong	1,054
	Roi Et	656
	Sakhon Nakhon	884
	Surat Thani	2,084
	Sukhothai	1,602
	Samui	12,306
	Tak	15
	Trang	2,584
	Ubon Ratchathani	2,442
	Udon Thani	2,356
	Utapao	2,740
Total		309,984

Source: International airport : Airport Authority
Local airport : Department of Aviation

3) Emission Factor

The method to estimate the SOx emission of aircraft is based on the "Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft(USEPA)".

The sulfur contents and specific gravity of fuel are shown in Table 4.2.1.26.

The equation to calculate emissions for each aircraft type is listed below.

$E_{ij} = TIM_{jk} \times EF_{ijk}$

Where

E_{ij} = total emissions of pollutant i, in kilograms, produced by aircraft type j, for one LTO cycle

TIM_{jk} = time in mode for k, in minutes, for aircraft type j (shown in Table 4.2.1.28)

EF_{ijk} = emission load for pollutant i, for mode k, in kilograms per minutes, for aircraft type j (shown in Table 4.2.1.27)

Table 4.2.1.26 Sulfur Contents and Specific Gravity of Fuel

Items	Unit	Value	Note
Sulfur Contents in fuel	Wt%	0.062	USEPA (Dickson and Sturm, 1997)
Specific gravity of fuel	Kg/Liter	0.78	

Table 4.2.1.27 SOx emission factor by aircraft type

Engine Modal Efs (kgs/min/Engine)		Number of Engine	TK	CB	AP	ID
Body Type			SOxef	SOxef	SOxef	SOxef
AIRBUS	A300	2	0.1503	0.1231	0.0412	0.0132
AIRBUS	A310	2	0.1392	0.1137	0.0404	0.0129
AIRBUS	A320	2	0.0681	0.0559	0.0189	0.0066
BEECH	B.99A	2	0.0035	0.0033	0.0018	0.0009
BOEING	B707	4	0.1522	0.1208	0.0448	0.0175
BOEING	B727	2	0.0967	0.0789	0.0278	0.0124
BOEING	B737	2	0.0715	0.0584	0.0207	0.0084
BOEING	B747	4	0.2884	0.2354	0.0813	0.0280
BOEING	B757	2	0.1099	0.0899	0.0310	0.0105
BOEING	B767	2	0.1542	0.1261	0.0439	0.0123
BRITAIRCOR	BAE-111	2	0.0232	0.0192	0.0067	0.0026
BRITAIRCOR	BAE-146	4	0.0464	0.0383	0.0134	0.0053
CONVAIR	CV640	2	0.0138	0.0110	0.0051	0.0034
DE HAVILLAND	DHC-6	2	0.0319	0.0265	0.0095	0.0037
FAIRCHILD	FH-227	2	0.0115	0.0102	0.0053	0.0034
FOKKER	F-27	2	0.0115	0.0102	0.0053	0.0034
FOKKER	F-28	2	0.0467	0.0382	0.0144	0.0075
FOKKER	F-100	2	0.0493	0.0408	0.0149	0.0071
LOCKHEED	L-1011	3	0.1927	0.1581	0.0563	0.0225
MCDONNELL DOUGLAS	DC10	3	0.2013	0.1664	0.0566	0.0193
MCDONNELL DOUGLAS	DC8	4	0.1482	0.1193	0.0445	0.0172
MCDONNELL DOUGLAS	DC9	2	0.0726	0.0589	0.0209	0.0088
MCDONNELL DOUGLAS	MD-11	3	0.2523	0.2007	0.0639	0.0191
NAMC	YS-11	2	0.0138	0.0110	0.0051	0.0034

Note: TK = Take-off; CB = Climb-out, AP = Approach; ID = Idle

Source: "Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft"(USEPA)

Table 4.2.1.28 Time-In-Mode

Mode of Operation	Time-In-Mode(min)
Taxi/idle-out	19.0
Take-off	0.7
Climb-out	17.9
Approach	24.0
Taxi/idle-in	7.0

Note: The height of Climb-out and Approach is 6000m.
Source : "Procedure for Emission Preparation Volume IV: Mobile Source"(USEPA,1992)

4) Estimated Emission

The estimated fuel consumption and SOx emission of aircraft for the year 2000 in the whole Thailand are shown in Table 4.2.1.29 and Figure 4.2.1.15.

The fuel consumption and SOx emission of aircraft in the whole Thailand is about 1,900 kton/year and about 2,300 ton/year in the year 2000 respectively. The fuel consumption in Bangkok International Airport accounts for 78% of the total fuel consumption of aircraft. 78 % of SOx emission of aircraft in the whole Thailand is emitted from Bangkok International Airport.

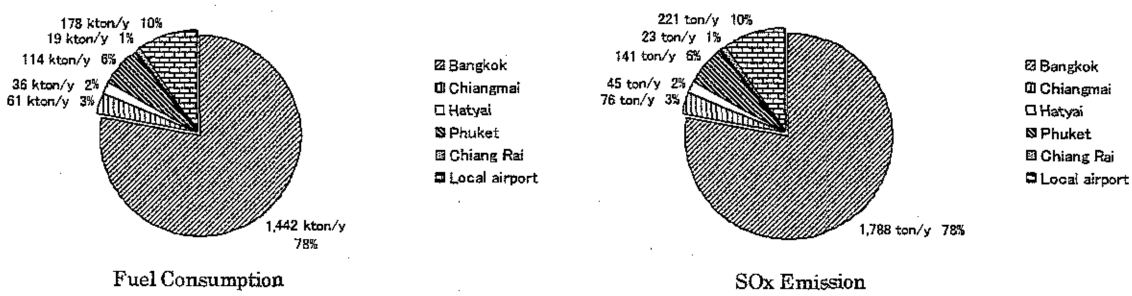


Figure 4.2.1.15 Fuel Consumption and SOx Emission of Aircraft in the Whole Thailand in the Year 2000

Table 4.2.1.29 Fuel Consumption and SOx Emission of Aircraft in the Year 2000

Airport		Fuel Consumption ktons/year	SOx Emission ton/year
International airport	Bangkok	1442	1,788
	Chiangmai	61	76
	Hatyai	36	45
	Phuket	114	141
	Chiang Rai	19	23
Local airport	Buri Ram	1	1
	Chumphon	0	0
	Hua Hin	21	27
	Khon Kaen	12	14
	Krabi	4	5
	Korat	9	11
	Lampang	6	7
	Mae Hong Son	4	5
	Mae Sot	1	2
	Nakhon Phanom	2	3
	Nakhon Si Thammarat	1	2
	Nan	2	2
	Narathiwat	2	3
	Pattani	0	0
	Phechabun	1	1
	Phitsanulok	20	24
	Pharae	3	3
	Ranong	1	2
	Roi Et	2	2
	Sakhon Nakhon	3	3
	Surat Thani	6	8
	Sukhothai	5	6
	Samui	36	45
	Tak	0	0
	Trang	4	5
	Ubon Ratchathani	13	16
	Udon Thani	12	15
	Utapao	8	10
	Sub Total	178	221
Total		1851	2295

Note: For ATMOS2, height of Climb-out and Approach is 6000m.

4.2.1.5 SOx Emission of Mobile Sources for the Year 2000 in the Whole Thailand

The Summary of SOx emission of mobile sources for the year 2000 in the whole Thailand is shown in Table 4.2.1.30. The estimated total annual SOx emission of mobile sources is about 18,000 ton/year. The share of each region in the total SOx emission is shown in Figure 4.2.1.16. The SOx emission of the BMR is about 7,400 ton/y, which accounts for about 40% of the total SOx emission.

The Share of each mobile source in the total SOx emission is shown in Figure 4.2.1.16. The share is 54% for vehicles on roads, 29% for ships, 13% for aircraft, 0.6% for railways and 3% for area sources like traffic in local areas.

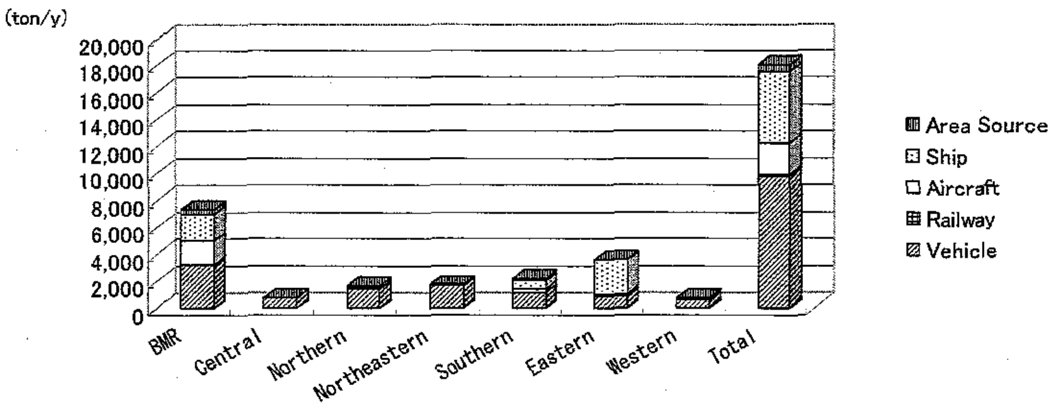


Figure 4.2.1.16 SOx Emission of Mobile Sources for the Year 2000 in the Whole Thailand

Table 4.2.1.30 SOx Emission of Mobile Sources of the Year 2000 in the Whole Thailand

Unit: ton/year

Region	Vehicle			Rail-way	Air-craft	Ship			Other	Total
	Gasoline	HSD	total	HSD	Jet Fuel	HSD	Fuel Oil	total	Area Source	
BMR	1,425	1,822	3,247	17	1,788	11	1,929	1,940	377	7,369
Central	166	566	732	23					23	779
Northern	452	995	1,447	32	150					1,629
Northeastern	432	1,205	1,636	34	66					1,736
Southern	346	759	1,104	31	254	16	690	706	95	2,190
Eastern	241	701	943	13	10	9	2,563	2,572	67	3,604
Western	155	491	647	19	27	6	67	73	16	781
Total	3,217	6,539	9,756	169	2,295	42	5,248	5,290	578	18,088

Note: Aircraft emission is estimated in LTO Cycle from 0m to 6000m.
HSD: High Speed Diesel

The Summary of fuel consumption of mobile sources for the year 2000 in the whole Thailand is shown in Table 4.2.1.31 and Figure 4.2.1.17.

The estimated total annual fuel consumption of mobile sources is 16,700 kton/year.

In comparison with the fuel consumption statistics for the year 2000, the estimated fuel consumption of total mobile sources is almost equal to the statistics. But, the estimated fuel consumption of aircraft is about two thirds of the statistics, and the one of ships is about one fourth.

When considering the reasons for why the fuel consumption of aircraft and ships is considerably less than the statistics, the fuel consumption of aircraft is estimated only by the LTO cycle, not the cruising, as the aircraft cruising height is about 10,000 m which is above the mixing height of the ATMOS2 model, 6,000m. The fuel consumption of vessels in the ship category is estimated only by loading, arriving and departing from the ports, not by cruising in the sea routes outsides the ports. In the ATOMOS2 model, the SOx emission of vessels in cruising in the Asian Sea, which includes SOx emission not only of Thai vessels but also from the other countries, will be considered based on the study of the Iowa University in the year 2000.

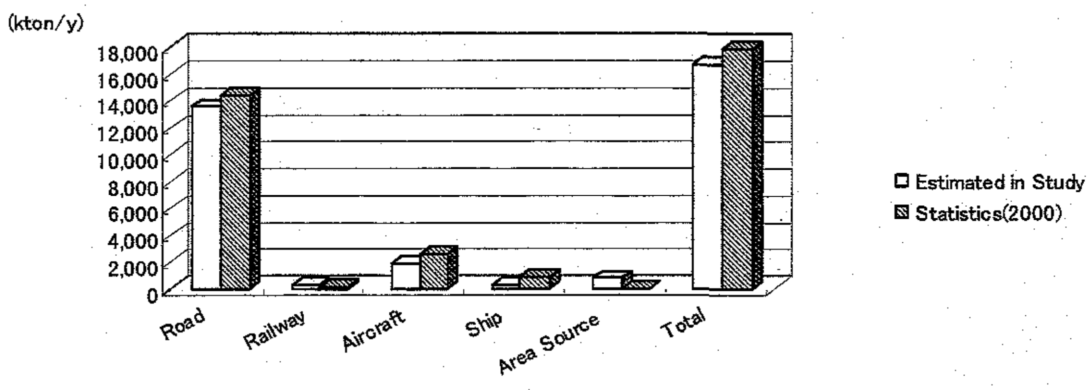


Figure 4.2.1.17 Fuel Consumption of Mobile Sources for the Year 2000 in the Whole Thailand

Table 4.2.1.31 Fuel Consumption of Mobile Sources for the Year 2000 in the Whole Thailand

Unit: kton/year

Item	Vehicle	Railway	Aircraft	Ship	Area Source	Total
Estimated in Study	13,605	242	1,851	214	759	16,672
Statistics(2000)	14,364	96	2,640	825	0	17,926

Note: Statistics(2000) : Ministry of Commerce

4.2.2 Mobile Sources Inventory for the Year 2000 in the BMR

4.2.2.1 Vehicles

1) Outline

The flow of NOx and SOx emission estimations of vehicles for the year 2000 in the BMR is shown in Figure4.2.2.1.

The database of traffic data and the emission factor in the Airviro system is updated using the traffic volume and traveling speed by link estimated based on the traffic assignment of "Urban Rail Transportation Master Plan (URMAP,2001) " report in OCMLT, and using the fleet mix (ratio by vehicle type) and the hourly fluctuation of traffic volume by link in the 1996 database of Airviro system.

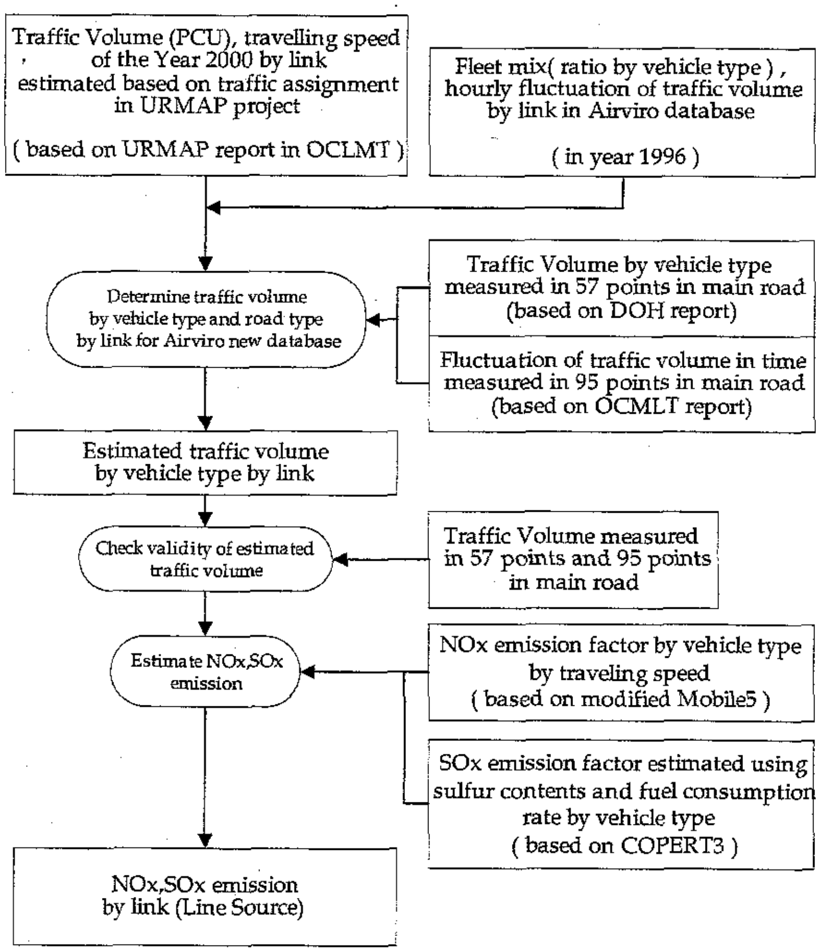


Figure 4.2.2.1 Flow of SOx and NOx emission estimations of vehicles for the Year 2000 in the BMR

Using the latest traffic data measured in 152 points on main roads in the BMR in the year 2000, the fleet mix and the hourly fluctuation of traffic volume of the 1996 database of the Airviro system is updated. And the validity of the used traffic assignment data can be checked by comparing with the latest measured traffic data.

The details of the updated Airviro database are explained in Chapter 6 "Model Simulation".

The SOx emission of vehicles in the BMR is estimated using the vehicle kilometer by link calculated by the traffic volume and the link length in the updated database of the Airviro system, and using SOx emission factor based on the actual sulfur contents of fuel and the fuel consumption rate calculated by COPERT3.

The NOx emission of vehicles in the BMR is estimated using the vehicle kilometer by link and the NOx emission factor by vehicle type and by the traveling speed calculated using on Mobile 5.

2) Traffic Data

The vehicle kilometers for the year 2000 by vehicle type in the BMR are shown in Table 4.2.2.1, which are estimated using the Airviro database updated based on the traffic assignment data in the URMAP report of OCMLT. The location of roads is shown in Figure 4.2.2.2.

The annual vehicle kilometers of the BMR is about 47,000 million vehicle-kilometers/year in the year 2000. The share of Bangkok is about 50% in the total vehicle kilometers of the BMR. As for the share of each vehicle type in the total vehicle kilometers, the share is 43% for gasoline passenger cars, 7% for diesel passenger cars, 15% for motorcycles, 15% for light trucks, 10% for heavy trucks and 7% for buses.

Table 4.2.2.1 Vehicle Kilometers by Vehicle Type in the BMR in the Year 2000

Province	Vehicle Kilometers by vehicle type (Million Vehicle-Kilometers/year)									
	PS(G)	Taxi (G)	Taxi (LPG)	PS(D)	Light Truck	Bus	Heavy Truck	MC	Tuk-Tuk	total
Bangkok	10,724	301	211	1,407	3,112	1,454	2,106	3,368	215	22,899
Nonthaburi	1,427	40	28	258	477	265	370	435	28	3,326
Pathum Thani	2,958	83	58	581	844	547	719	818	52	6,662
Samut Prakan	2,177	61	43	322	689	352	515	744	47	4,951
Nakhon Pathom	1,746	49	34	370	1,432	408	784	1,238	79	6,140
Samut Sakhon	1,100	31	22	224	503	202	301	484	31	2,897
BMR	20,132	565	396	3,162	7,058	3,228	4,794	7,086	452	46,874

Note: Estimated based on traffic assignment data of the URMAP report in OCMLT

Figure 4.2.2.2 Location of Mobile Source in the BMR in Year 2000

3) Emission Factor

(1) Method

As for the emission factors of SOx and the fleet data in the BMR, the same methods of calculation and the same results as discussed before, the emission factors of SOx and the fleet data in Thailand were considered to be applicable to the BMR, therefore the method for the NOx emission factor estimates is focused upon here.

In 1994, PCD studied the emission factor of NOx as one of the air pollutants from road transport and developed their emission factor calculation program, modified from MOBILE5, which US-EPA established.

Figure 4.2.2.3 shows the general workflow of the NOx emission factor calculation used in this study. Vehicle types were divided into 3 categories, gasoline or diesel fuelled vehicles, motorcycles and Tuk-tuks/Taxis(LPG), and different methods were applied for them in consideration of their specific property and the limitation of data availability.

Principally, emission factors estimated for each model year were based on emission test data of the vehicles under the emission standards enforced at that year. And when no test data was available for emission standard enforcement periods in the case of no test implemented or emission factors for future emission standards, they were estimated from previous or subsequent emission factor with the rate of change between two emission standards being complied.

Then the emission factor calculated by each vehicle type and each model year, were compiled with fleet data, age distribution and mileage distribution, by MOBILE5 and the emission factors of the year 2000 were calculated by vehicle type.

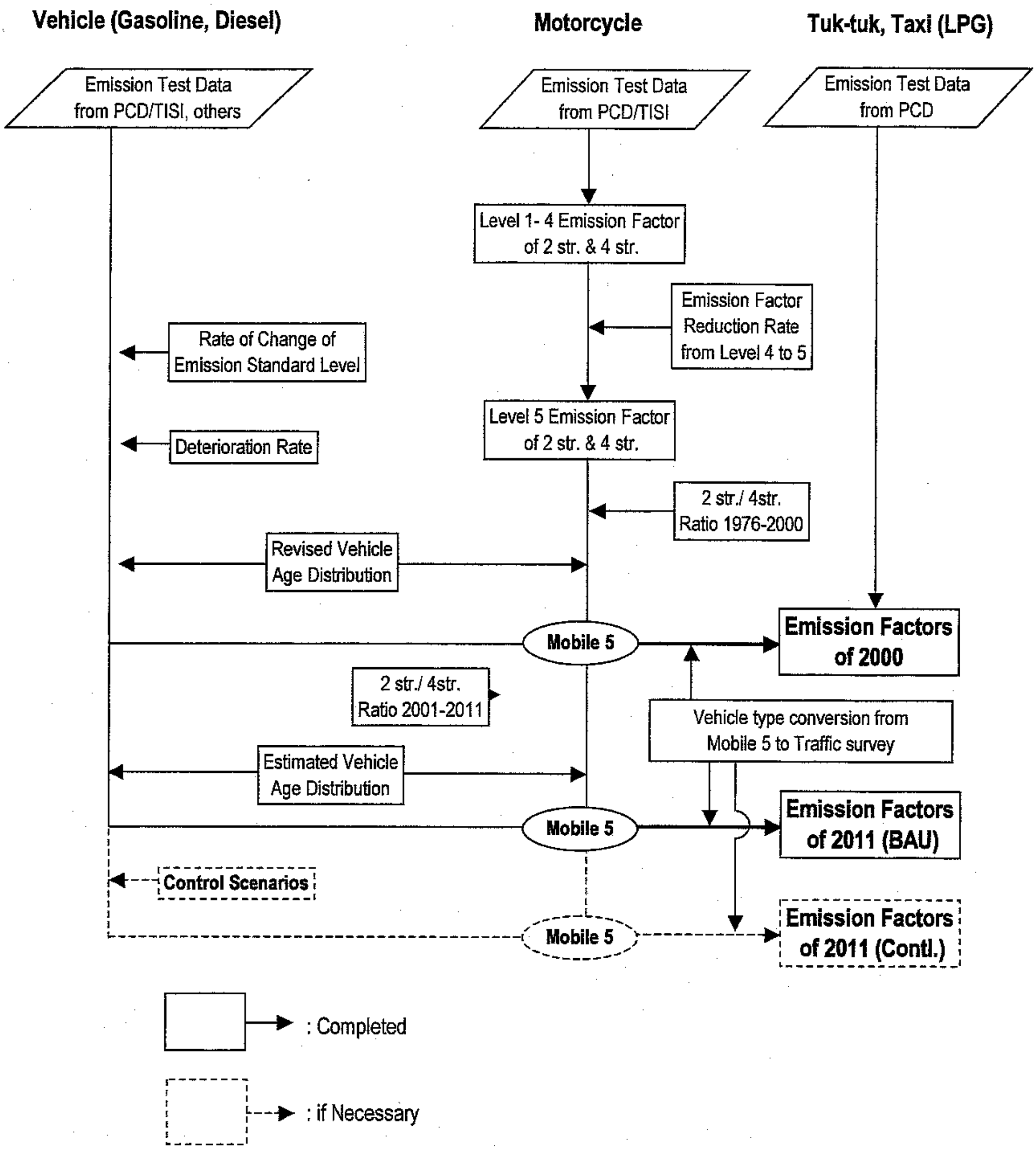


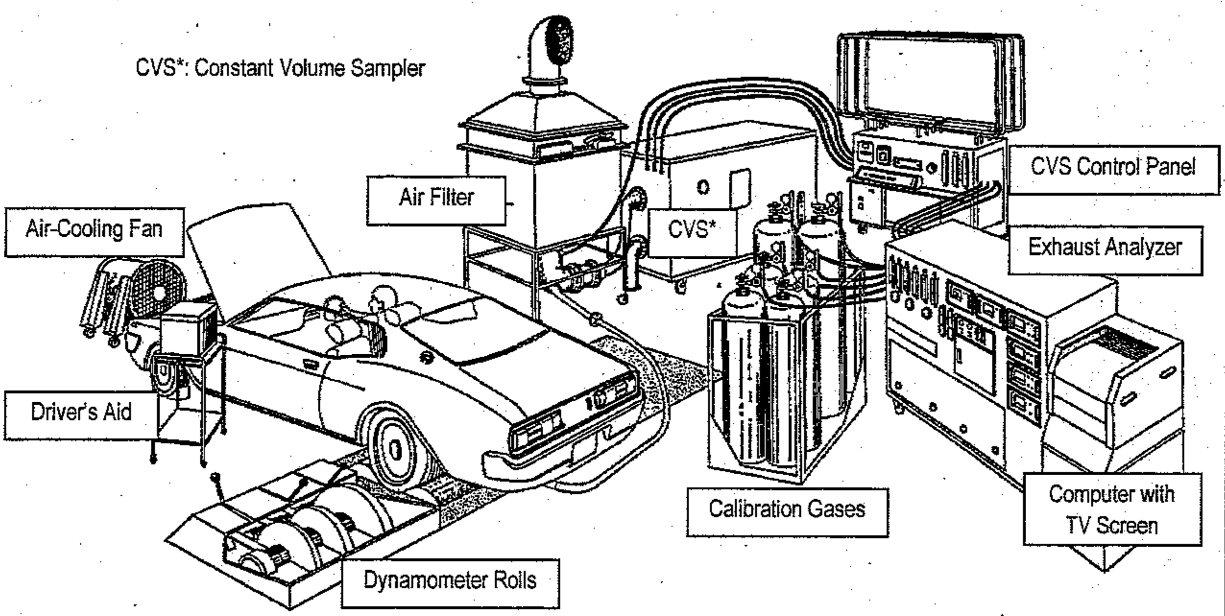
Figure 4.2.2.3 General Workflow of NOx Emission Factor Calculation

BOX: Emission Test by Chassis Dynamometer

The chassis dynamometer is used for exhaust emissions tests. The test vehicle is placed on the roll of the chassis dynamometer, which allows the wheels to spin and uses inertia weights and horsepower settings to simulate real world driving conditions.

A heated transfer hose is attached to the tail pipe of the test vehicle to collect the exhaust gases and direct them into the constant volume sampler (**CVS**). This system dilutes the exhaust with ambient air and directs a portion of the mixture for analysis.

Once the test vehicle is properly mounted with the sampling system in place and all the controls and instrumentation are set, the vehicle is driven in the driving cycle, such as ECE+EUDC Mode, specified in the relevant standard, such as TIS. The driver starts the engine and attempts to follow the driving cycle shown on a computer monitor (Driver's Aid in Figure below) by accelerating and braking the vehicle.



Typical Physical Layout of an Chassis Dynamometer Emission Testing Facility[1]

1 Hisashi, K. 1973. "Latest Automotive Emission Reduction Technology and Regulation."

(2) Vehicles (Gasoline, Diesel)

Figure 4.2.2.4 shows the detailed workflow of the NOx emission factor calculation for vehicles. Emission test data of LDGV, LDDV, LDDT and HDDV were collected as shown in Table 4.2.2.2 and screened by emission standards to be complied as shown in Table 4.2.2.2. The median of those screened test data were then considered to represent the emission factors of vehicles in each emission standard and were adopted. In the subsequent step, emission factors without test data, like ones from the pre-emission standards or EURO 3, were estimated and then a set of emission factors by vehicle type and model year were completed.

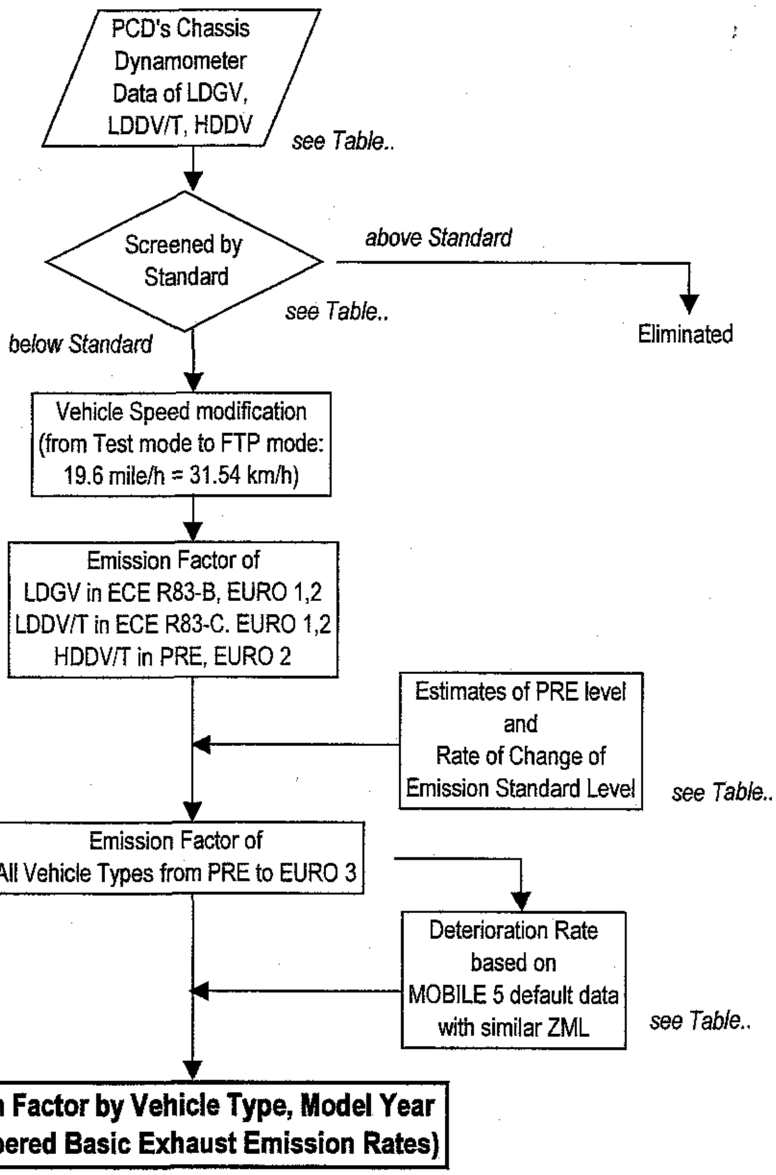


Figure 4.2.2.4 Detailed Workflow of NOx Emission Factor Calculation for Vehicles

Table 4.2.2.2 Test Data by Chassis Dynamometer

Level	PRE	1	2	3	4	5	6	7	Total
LDGV	-	*(3/3)*	*189/224*	*151/209*	*33/37*	*143/169*	*35/38*	*(8/10)*	519 / 680
	PRE		**ECE R83-B**	**EURO 1**		**EURO 2**		**EURO 3**	
	-		**189 / 224**	**184 / 246**		**178 / 207**		-	
LDDV	-	*6/14*	*0/4*	*10/12*	*11/248*	*87/89*	-		114 / 367
	PRE	**ECE R83-C**	**EURO 1**		**EURO 2**		-		
	-	**6 / 14**	**10 / 16**		**98 / 337**		-		
LDDT	-	*11/11*	*1/1*	*7/8*	*25/37*	*20/26*	-		64 / 83
	PRE	**ECE R83-C**		**EURO 1**		**EURO 2**	-		
	-	**12 / 12**		**32 / 45**		**20 / 26**	-		
HDDV/T	*6*	*8*	*-*	*7*	-				21
	PRE		**EURO 1**	**EURO 2**	-				
	14		**-**	**7**	-				

Note: (No. of samples screened) / (Total No. of samples collected)
The Standards here mean Emission standards of (HC + NOx) or NOx
There is no Emission Standard for HDDV/T emission level by Chassis Dynamometer

Table 4.2.2.3 Thai Emission Standards of Equivalent EU Emission Standards

Thai Industiral Standard		Lv.	EURO	EU Directive	Equivalent ECE Regulation
Light-Duty Gasoline Vehicle	TISI.1085-2535(1992)	1	---	83/351/EEC	ECE R15-04
	TISI.1120-2535(1992)	2	---	88/76/EEC	ECE R83(B)
	TISI.1280-2538(1995)	3	I	91/441/EEC	ECE R83-01(B)
	TISI.1365-2539(1996)	4	I	93/59/EEC	ECE R83-02
	TISI.1440-2540(1997)	5	II	94/12/EC	ECE R83-03
	TISI.1870-2542(1999)	6	II	96/69/EC	ECE R83-04
	---	7	III	98/69/EC(A)	ECE R83-05
	---	8	IV	98/69/EC(B)	ECE R83-05
Light-Duty Diesel Vehicle / Truck	TISI.1140-2536(1993)	1	---	88/76/EEC	ECE R83(C)
	TISI.1285-2538(1995)	2	I	91/441/EEC	ECE R83-01(C)
	TISI.1370-2539(1996)	3	I	93/59/EEC	ECE R83-02
	TISI.1435-2540(1997)	4	II	94/12/EC	ECE R83-03
	TISI.1875-2542(1999)	5	II	96/69/EC	ECE R83-04
	---	6	III	98/69/EC(A)	ECE R83-05
	---	7	IV	98/69/EC(B)	ECE R83-05
Heavy-Duty Diesel Vehicle / Truck	TISI.1180(1)-2538(1995)	1	---	---	ECE R49-01
	TISI.1290-2538(1995)	2	I	91/542/EEC(A)	ECE R49-02(A)
	TISI.1295-2541(1998)	3	II	91/542/EEC(B)	ECE R49-02(B)
	---	4	III	1999/96/EC(A)	---

Table 4.2.2.4 shows the reduction rate of the NOx emission factor from EURO 1 for LDGV, LDDV, LDDT and HDDV. With these rates of changes between the emission standards, the emission factors in EURO 2 of LDGV, LDDV, LDDT were reduced for their emission factors in EURO 3, which have not been enforced as yet[1], and the one in EURO 2 of HDDV was increased for that in EURO 1, where no test data were available.

Table 4.2.2.4 Reduction rates of NOx Emission Factor in EURO 2 onward from EURO 1

Vehicle category	EURO level	EU directive	Standard (HDDV:	g/km g/kWh)	Standard Red.Rate*	E.F. Red./Incrs. Rate
Gasoline Passenger Cars (LDGV)	I	91/441/EEC	HC+NOx	0.97	0%	
	II	94/12/EC	HC+NOx	0.50	55%	
	III	98/69/EC I	NOx	0.15	75%	X 57%
	IV	98/69/EC II	NOx	0.08	86%	
Diesel Passenger Cars (LDDV)	I	91/441/EEC	HC+NOx	0.97-1.70	0%	
	II	94/12/EC	HC+NOx	0.70-1.20	38%	
	III	98/69/EC I	NOx	0.50-0.78	44%	X 89%
	IV	98/69/EC II	NOx	0.25-0.39	72%	
Light Diesel Commercial Vehicles (LDDT)	I	93/59/EEC	HC+NOx	0.97-1.70	0%	
	II	96/69/EC	HC+NOx	0.70-1.20	34%	
	III	98/69/EC I	NOx	0.50-0.78	49%	X 77%
	IV	98/69/EC II	NOx	0.25-0.39	75%	
Heavy Duty Diesel Vehicles (HDDV)	I	91/542/EEC(A)	NOx	8.00	0%	X 114%
	II	91/542/EEC(B)	NOx	7.00	13%	
	III	1999/96/EC(A)	NOx	5.00	38%	X 71%
	IV	1999/96/EC(B1)	NOx	3.50	56%	

cf. Samaras, Z., 2001. An empirical method for predicting exhaust emissions of regulated pollutants form future vehicle technologies

Figure 4.2.2.5 to 4.2.2.7 shows the emission factors and test data of LDGV, LDDV, LDDT and HDDV. As for the emission factors of PRE level of LDGV, LDDV and LDDT,

LDGV: Test data of level 1 (ECE R15-04), which was not enforced, were based.

LDDV, LDDT: Even the ones of ECE R83 showed higher emission levels than the PRE level of the default basic emission rates in MOBILE5 so that the ones in the PRE level were considered as the same level.

Table 4.2.2.5 shows vehicle type conversions from MOBILE5 to traffic data and Table 4.2.2.6 shows emission factors and deterioration rates by vehicle type and model year. As for the deterioration rates, the default value of MOBILE5 with the similar emission factor of zero mile traveled were adopted[2].

[1] As shown in Table 4.2.2.2 "Test Data by Chassis Dynamometer", some test data of LDGV in EURO 3 were available. However, the median of them showed a higher level than EURO 2 though EURO 3 must be more stringent than EURO 2. This reason was considered for those test vehicles fuelled by gasoline of preset quality, though EURO 3 reassumes a more refined one so that they were eliminated.

[2] Almost all of the test data did not have odometer records and it was considered that the vehicle would likely have the default deterioration rates of the default ZML, which was similar to the estimated.

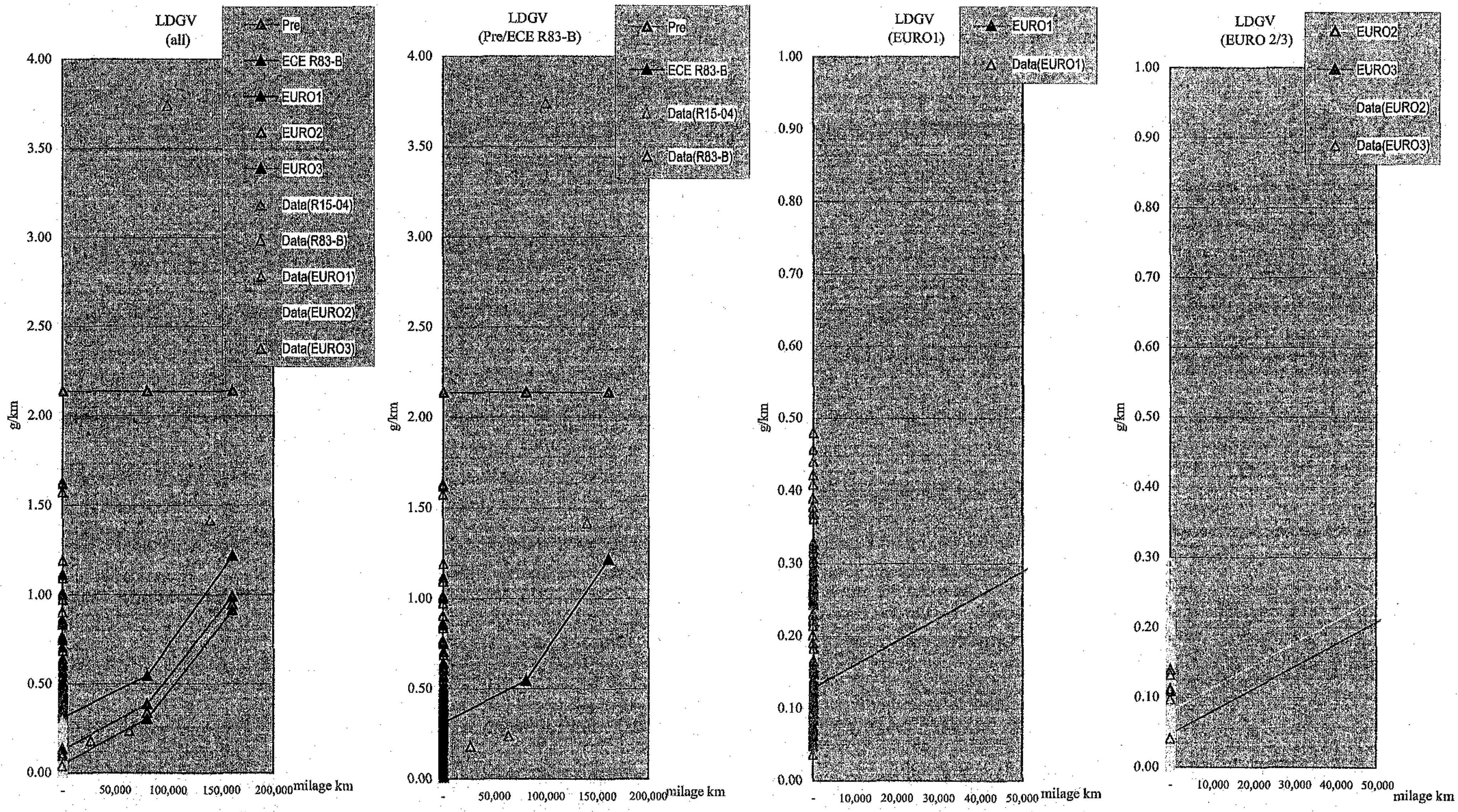


Figure 4.2.2.5 NOx Emission Factors and Test Data (LDGV)

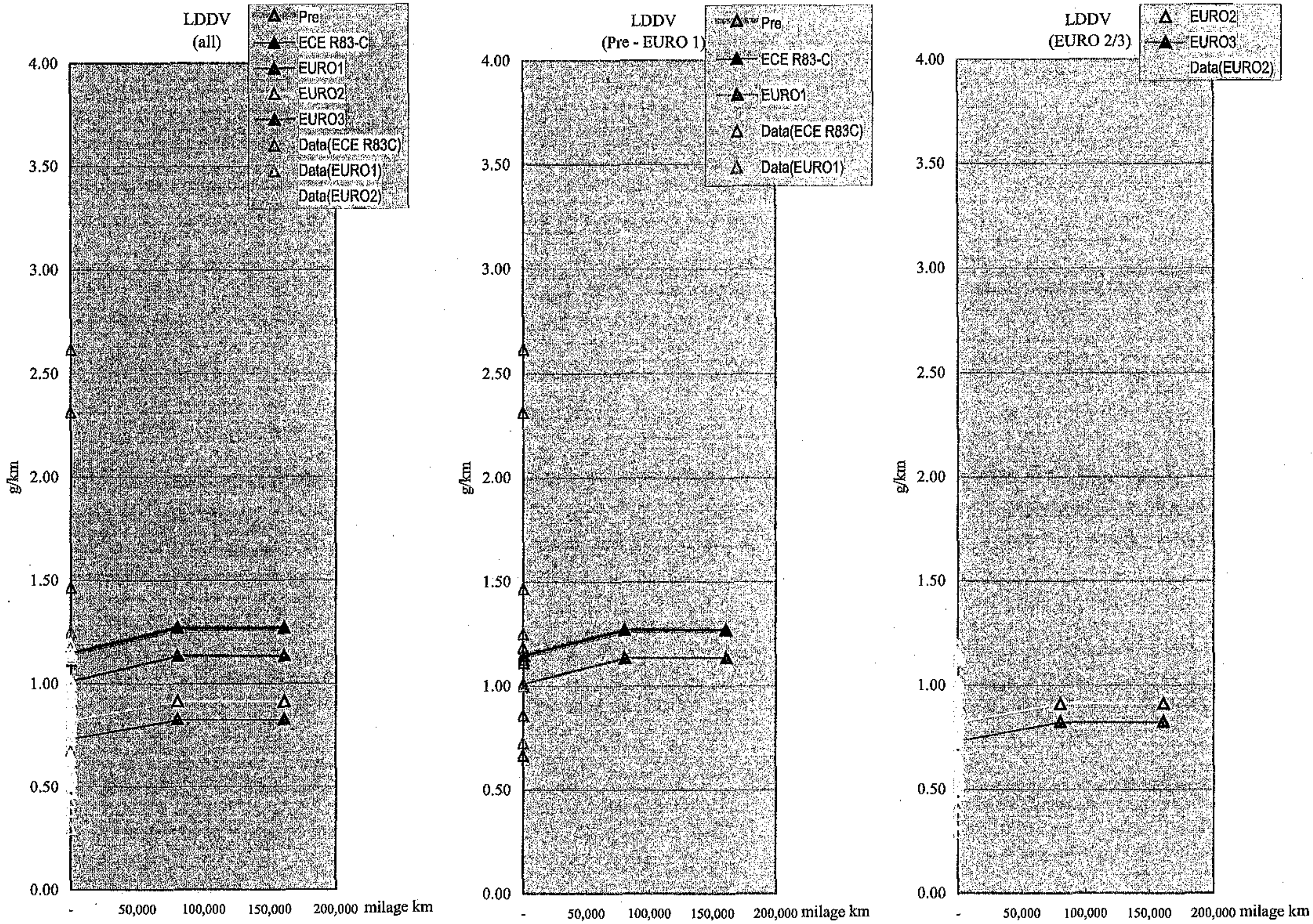


Figure 4.2.2.6 NOx Emission Factors and Test Data (LDDV)

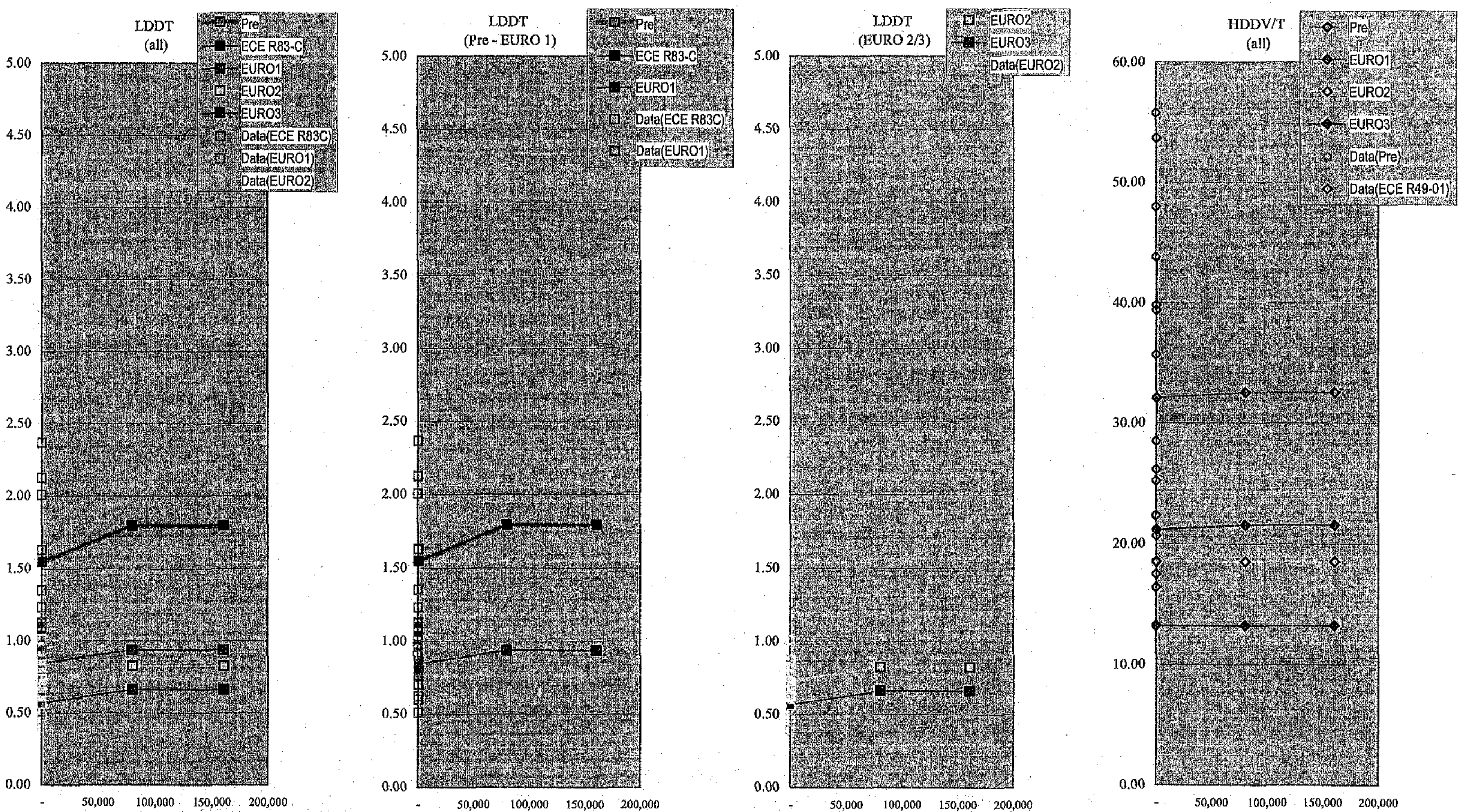


Figure 4.2.2.7 NOx Emission Factors and Test Data (LDDT, HDDV/T)

Table 4.2.2.5 Vehicle Type Conversion from MOBILE5 to Traffic Data

Vehicle Type of Mobile 5		Equivalent Vehicle Type of Traffic Data	
1	LDGV (incl. Taxi (Gasoline))	Car + Taxi	- Gasoline/Diesel Ratio from Registered Vehicle Data of DLT (rows 1–3)
2	LDGT	*- negligible*	
3	LDDV	Car	
4	LDDT	Light Truck (Pick-up)	
5	HDDV	Medium + Heavy Truck, Medium + Heavy Bus	
6	MC	Motorcycle	
7	Taxi (LPG)	Taxi	- Gasoline/LPG Ratio from DLT (rows 7–8)
8	Tuk-tuk (LPG)	Samlor	

Vehicle Type Definition for Mobile 5		
1	LDGV	Light-duty Gasoline Passenger Cars
2	LDGT	Light-duty Gasoline Trucks
3	LDDV	Light-duty Diesel Passenger Cars
4	LDDT	Light-duty Diesel Trucks < 3.86t Gross Vehicle Weight Rating
5	HDDV	Heavy-duty Diesel Vehicles > 3.86t Gross Vehicle Weight Rating

Vehicle Type Definition for Traffic Data of BMR		
1	Car	Passenger Car
2	Taxi	Taxi
3	Light Truck (Pick-up)	4 wheels
4	Medium Truck	>= 6 wheels
5	Heavy Truck	>= 10 wheels
6	Light Bus	Micro Bus, Green Bus
7	Heavy Bus	Urban Bus, Coach
8	MC & Samlor	2, 3 wheels

Table 4.2.2.6 Emission Factors and Deterioration Rates by Vehicle Type and Model Year

unit:g/mile (except HDDV: g/BHP-hr)

Vehicle category	Std.	Imp.Year	Base	det.1	det.2	Standard	
LDGV/Taxi (Gasoline)	Pre	-	3.440	0.000	0.000	—	
	ECE R83-B	1995	0.500	0.075	0.216	HC+NOx	5.957
	EURO1	1996	0.207	0.083	0.194	HC+NOx	1.561
	EURO2	1999	0.129	0.083	0.195	HC+NOx	0.805
	EURO3	2004	0.077	0.083	0.195	NOx	0.241
LDDV	Pre	-	1.843	0.040	-	—	
	ECE R83-C	1995	1.843	0.040	-	HC+NOx	5.957
	EURO1	1996	1.625	0.040	-	HC+NOx	2.736
	EURO2	2001	1.319	0.030	-	HC+NOx	1.931
	EURO3	2004	1.177	0.030	-	NOx	1.255
LDDT	Pre	-	2.489	0.080	-	—	
	ECE R83-C	1995	2.489	0.080	-	HC+NOx	13.90
	EURO1	1997	1.356	0.030	-	HC+NOx	2.736
	EURO2	2001	1.177	0.030	-	HC+NOx	1.931
	EURO3	2004	0.916	0.030	-	NOx	1.255
HDDV/T	Pre	-	20.381	0.057	-	—	
	EURO1	1998	16.742	0.057	-	NOx	8.0
	EURO2	2000	14.650	0.000	-	NOx	7.0
	EURO3	2005	10.464	0.000	-	NOx	5.0

Note 1: EURO 2- Standards of LDGV, LDDV, and LDDT, which limit HC+NOx, and their NOx E.F. are not directly comparable.

2: In case that Emission Standards are different among Vehicle specs, the largest emission levels are shown.

3: E.F. of HDDV/T based on Test Data of Chassis Dynamometer and Standards of Engine Bench Test are not comparable.

(3) Motorcycles and Tuk-tuks, Taxis(LPG)

Figure 4.2.2.8 shows the detailed workflow of the NOx emission factors calculation for MCs and Tuk-tuks, Taxis(LPG). The test data of MCs were treated separately since they were identified by MCs of 2-stroke or 4-stroke engines and test data showed completely different results, where emission data of 4-strokes were around 10 times higher than the ones of 2-stroke. Then the emission factors of MCs were estimated separately for 2 or 4-strokes and combined by their shares in the total market.

As for Tuk-tuks, based on some test data collected, the emission factor was estimated as one value for all speed ranges and all model years due to its limited information.

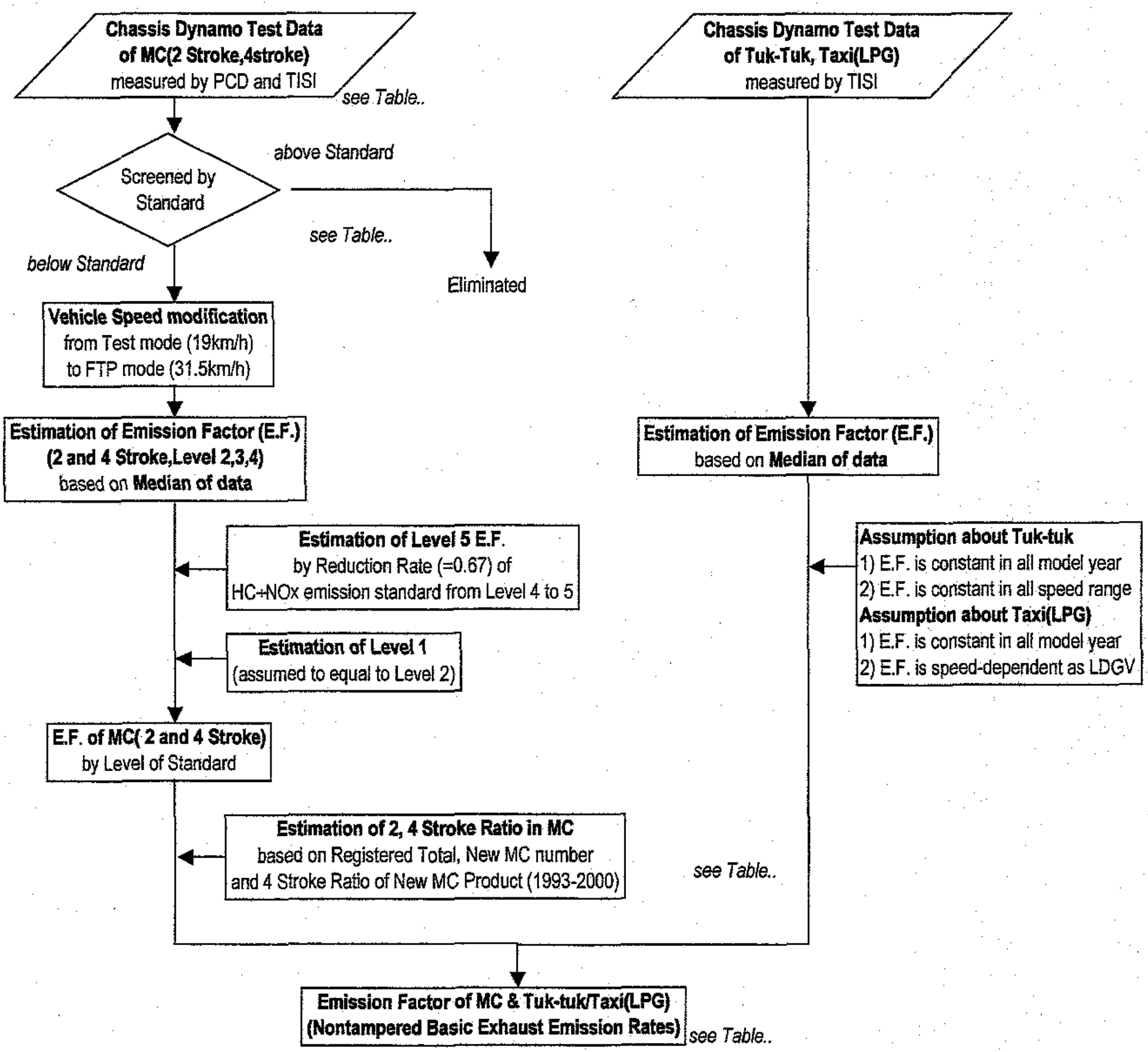


Figure 4.2.2.8 Detailed Workflow of NOx Emission Factors calculation for MCs and Tuk-tuks/Taxis(LPG)

For estimating of the emission factor of 2 or 4-stroke MCs, a similar method as discussed in the emission factors of Vehicles was applied. Test data by the Chassis Dynamometer are shown in Table 4.2.2.7 and emission standards to screen them are shown in Table 4.2.2.8.

As for the total share of 4-strokes, they were estimated on a basis of new-registered numbers during 1993-2000 and the assumption that the ratios of the years before 1993 were assumed to be the one of 1993.

Table 4.2.2.9 shows the share of each year from 1976 to 2000 based on the accumulated number of them.

Table 4.2.2.7 Test Data by Chassis Dynamometer

Level	PRE, 1	2	3	4	Total
2 Stroke	0 / 0	19 / 23	29 / 36	16 / 19	64 / 78
4 Stroke	0 / 0	6 / 6	308 / 310	49 / 49	363 / 365

Note: (No. of samples below standard) / (Total No. of samples collected)
The Emission Standard here means Emission standard of (HC) or (HC + NOx)

Table 4.2.2.8 Thai Motorcycle Emission Standard

Thai Industiral Stnd.		Lv.	EU Directive or others	EF Change Rate
Motor-cycl	TISI 1105-2535(1992)	1	ECE R 40-00	
	TISI 1185-2536(1993)	2	ECE R 40-01	
	TISI 1305-2538(1995)	3	CO<=13g/km, HC<=5g/km	
	TISI 1355-2539(1996)			
	TISI 1360-2539(1996)			
	TISI 1650-2541(1998)	4	CO<=4.5g/km, HC+NOx<=3g/km	
	—	5	CO<=3.5g/km, HC+NOx<=2g/km	X 67%

Table 4.2.2.9 Shares of 2 or 4 Stroke in MCs

Year	Registered MC Number (Share of 4-storke:%)		New MC Number (Share of 4-storke:%)	
1976-1993	7,260,665	13%	-	-
1994	8,248,303	13%	1,091,216	13%
1995	9,314,840	14%	1,339,076	14%
1996	10,713,678	14%	1,247,906	18%
1997	11,649,959	15%	987,343	26%
1998	12,464,499	16%	533,848	44%
1999	13,244,961	17%	497,422	54%
2000	13,816,560	20%	682,929	70%

Figure 4.2.2.9 shows the test data of NOx and the emission factors calculated as a median of them. The emission factors of PRE-level and Level 1 were assumed to be approximate to the ones of Level 2, because it was considered that the NOx reduction technology of MCs had not been developed and installed when the volume of NOx emitted from MCs had not been noticed in the early stages while HC or CO, the pollutants caused by incomplete combustion, have aroused careful attention.

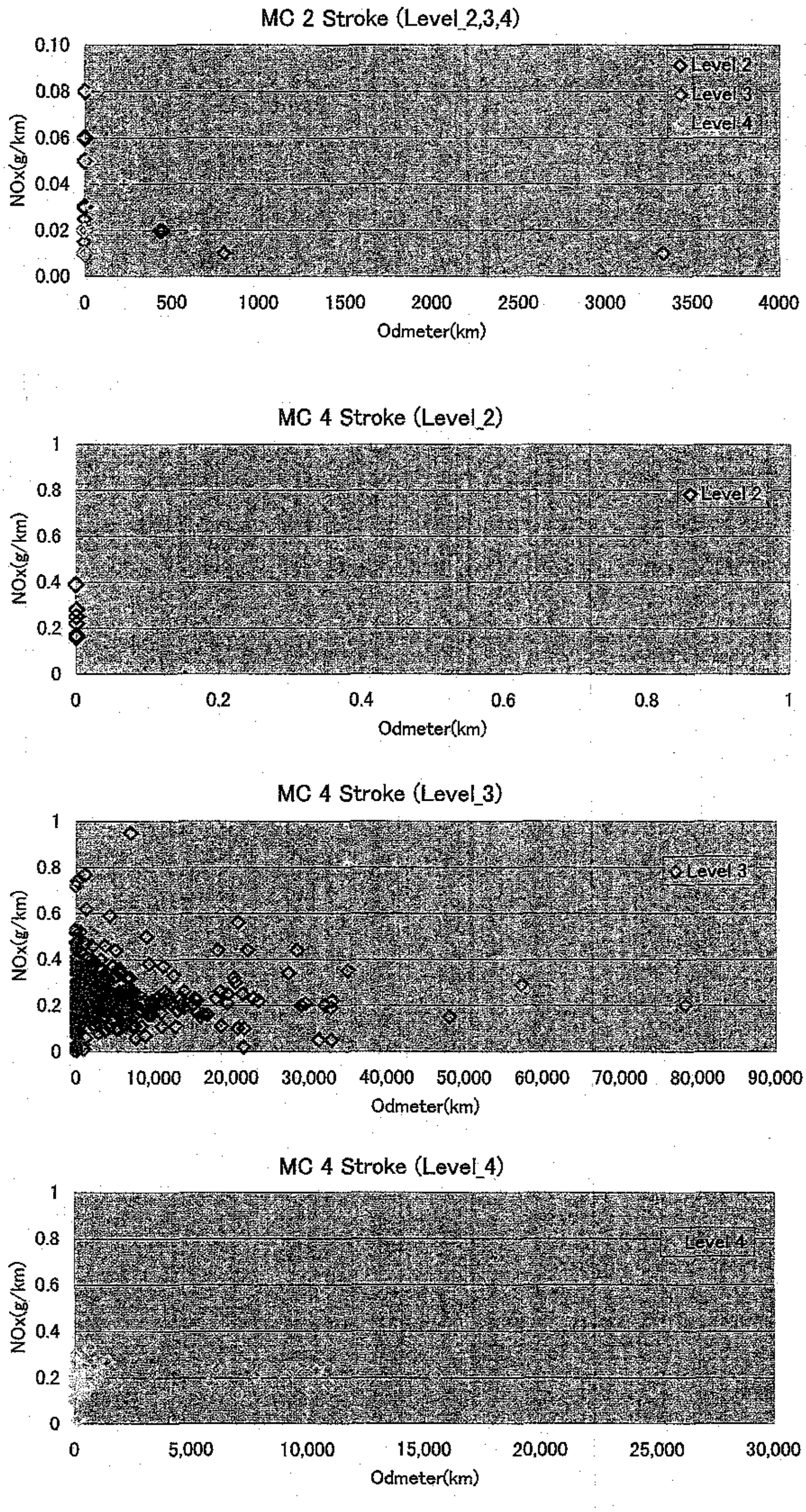


Figure 4.2.2.9 NOx Emission Factors and Test Data (MCs 2,4 strokes)