Table 3-2 (3) Results of the traffic survey

Station...T5 Date...1988/7/13-14 Direction...Both

Time	Diesel			Gaso-line	Others	Total
	LV	HV	LV+HV			
10 : 00~11 : 00	525	313	838	313	361	1.512
11 : 00~12 : 00	503	370	873	298	389	1.560
12 : 00~13 : 00	374	239	613	242	284	1.139
13 : 00~14 : 00	419	233	652	301	385	1.338
14 : 00~15 : 00	424	321	745	309	376	1.430
15 : 00~16 : 00	421	422	843	386	350	1.579
16 : 00~17 : 00	556	275	831	371	363	1.565
17 : 00~18 : 00	517	201	718	510	497	1.725
18 : 00~19 : 00	503	149	652	391	452	1.495
19 : 00~20 : 00	284	115	399	247	346	992
20 : 00~21 : 00	343	80	423	186	339	948
21 : 00~22 : 00	277	78	355	194	300	849
22 : 00~23 : 00	145	31	176	169	304	649
23 : 00~24 : 00	86	24	110	56	235	401
0 : 00~ 1 : 00	56	20	76	51	196	323
1 : 00~ 2 : 00	34	17	51	42	103	196
2 : 00~ 3 : 00	31	7	38	30	83	155
3 : 00~ 4 : 00	43	22	65	22	55	142
4 : 00~ 5 : 00	66	23	89	27	57	173
5 : 00~ 6 : 00	160	62	222	58	129	409
6 : 00~ 7 : 00	420	104	524	305	203	1.038
7 : 00~ 8 : 00	541	131	672	658	646	1.976
8 : 00~ 9 : 00	569	143	712	459	334	1.505
9 : 00~10 : 00	442	198	640	270	257	1.167
Total	7.739	3,578	11.317	5,896	7.054	24.257

Notes : LV = Light Vehicle HV = Heavy Vehicle

Table 3-3 Results of the travel speed survey (unit; km/h)

[MS 1]

Inbound		Outbound	
TIME	SP.	TIME	SP.
10 : 05	51.9	10 : 00	46.4
10 : 30	44.7	10 : 15	49.6
11 : 00	46.3	11 : 05	45.2
12 : 05	43.5	12 : 10	47.4
12 : 10	42.6	12 : 20	45.3
13 : 10	45.8	13 : 05	44.7
14 : 00	45.3	14 : 05	50.0
15 : 05	41.3	14 : 15	50.0
15 : 30	39.1	15 : 00	49.7
16 : 00	44.6	15 : 25	45.9
17 : 10	43.4	16 : 08	41.6
18 : 40	43.9	17 : 05	43.6
19 : 45	46.5	19 : 35	45.4
20 : 00	52.6	20 : 15	43.1
20 : 25	49.7	21 : 00	45.5
21 : 15	49.7	21 : 10	49.7
21 : 40	50.9	21 : 45	62.2
22 : 10	53.2	22 : 20	52.6
23 : 00	54.9	22 : 30	56.6
0 : 10	57.6	23 : 15	58.8
1 : 00	63.7	0 : 05	61.3
2 : 10	62.6	1 : 06	65.3
3 : 05	62.6	2 : 00	63.9
4 : 10	56.7	3 : 15	62.3
5 : 30	50.9	4 : 30	57.8
6 : 07	46.0	5 : 40	56.8
6 : 25	43.7	6 : 05	47.9
7 : 05	46.9	7 : 00	45.6
7 : 10	33.0	8 : 00	53.0
8 : 05	44.7	8 : 35	52.0
8 : 30	48.0	9 : 00	47.9
9 : 05	34.0	9 : 15	48.3
9 : 17	37.6	9 : 40	16.2
		9 : 45	4.0
		9 : 50	8.8
		10 : 00	12.1
A V E	47.8	A V E	46.6

[MS 4 - 1]

Inbound		Outbound	
TIME	SP.	TIME	SP.
11 : 15	43.5	11 : 00	43.4
11 : 45	48.9	11 : 10	50.6
18 : 50	48.3	18 : 10	44.4
0 : 40	48.6	0 : 00	50.1
8 : 30	35.0	8 : 00	34.2
A V E	45.9	A V E	44.5

[MS 4 - 2]

Inbound		Outbound	
TIME	SP.	TIME	SP.
11 : 05	59.0	11 : 00	57.9
11 : 10	71.4	11 : 08	61.4
18 : 00	44.2	18 : 03	39.7
18 : 05	49.5	18 : 10	49.3
0 : 03	64.8	0 : 07	63.2
0 : 12	63.4	0 : 02	60.4
6 : 20	56.8	6 : 10	55.2
6 : 32	48.4	6 : 15	51.4
A V E	57.2	A V E	54.8

[MS 5]

Inbound		Outbound	
TIME	SP.	TIME	SP.
11 : 08	36.0	11 : 05	63.7
17 : 07	48.0	17 : 03	91.7
23 : 09	65.8	23 : 10	65.2
8 : 03	66.7	8 : 02	80.5
A V E	54.1	A V E	75.3

TIME	STATION T1		STATION T2		STATION T3		STATION T4		STATION T5	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
10 : 00	42.1	39.3	8.3	15.6	25.7	23.8	21.9	34.6	27.7	30.0
10 : 30	45.0	45.0	13.0	19.3	15.0	22.2	21.0	25.0	34.9	27.0
11 : 00	37.9	19.5	17.0	23.8	13.9	3.4	31.2	27.5	28.6	26.5
11 : 30	44.1	45.0	13.4	23.1	13.8	4.1	27.1	28.8	29.5	32.7
12 : 00	43.5	44.7	21.5	21.1	21.1	9.0	31.1	35.0	27.0	36.0
12 : 30	40.0	20.0	21.1	21.9	21.2	5.1	35.4	32.3	36.0	27.0
13 : 00	32.7	30.0	25.2	23.9	20.0	5.1	43.3	39.0	26.5	26.7
13 : 30	45.0	51.1	25.2	25.6	21.2	2.3	47.5	27.0	35.0	27.7
14 : 00	28.9	40.0	11.7	24.3	25.2	4.8	42.5	41.7	30.0	25.1
14 : 30	51.4	56.4	16.6	20.7	25.2	24.0	35.8	46.1	23.8	19.4
15 : 00	45.0	45.0	19.9	19.2	19.0	19.6	35.8	41.5	27.1	20.0
15 : 30	44.3	25.7	16.5	14.7	24.0	18.5	17.9	25.4	36.0	44.7
16 : 00	45.0	17.1	17.2	17.8	27.0	19.0	59.9	29.3	35.9	22.5
16 : 30	44.6	15.9	21.1	18.0	40.0	40.0	37.1	30.4	29.9	25.4
17 : 00	37.9	24.0	21.2	16.3	24.0	36.0	26.2	52.4	22.3	22.3
17 : 30	48.7	42.2	18.4	21.1	30.0	32.7	27.0	35.5	32.7	26.7
18 : 00	40.0	44.9	23.8	20.0	40.0	45.0	33.3	44.2	44.3	36.7
18 : 30	50.4	40.0	22.2	20.9	24.0	31.9	40.3	42.4	32.2	31.4
19 : 00	45.0	44.4	23.7	22.5	32.4	34.2	24.6	25.2	23.3	24.0
19 : 30	51.4	44.0	29.1	24.9	29.3	31.7	35.9	30.9	34.8	20.8
20 : 00	55.4	56.8	29.6	27.7	35.0	38.6	28.1	28.7	27.1	32.7
20 : 30	58.0	55.3	27.7	31.5	36.0	42.8	32.5	27.6	28.9	24.0
21 : 00	59.2	60.0	27.4	32.1	32.7	38.1	25.7	36.5	27.3	30.0
21 : 30	68.1	64.6	41.2	32.4	35.2	37.9	40.3	35.1	25.7	35.0
22 : 00	64.6	60.0	38.7	35.6	45.0	40.0	35.4	49.3	45.0	42.4
22 : 30	60.0	60.0	31.9	29.8	45.0	42.9	30.8	49.7	39.5	35.9
23 : 00	60.0	60.0	44.6	31.6	44.3	39.7	39.6	44.2	31.2	32.7
23 : 30	62.8	49.3	44.6	35.7	43.7	43.3	36.0	50.5	40.0	30.0
0 : 00	55.4	79.1	45.3	41.9	43.7	42.6	35.8	57.3	25.4	27.3
0 : 30	48.0	54.7	39.5	34.9	51.4	45.0	52.7	36.4	30.0	27.7
1 : 00	51.4	47.6	43.4	37.8	42.8	43.3	29.9	40.5	22.2	20.6
1 : 30	72.0	57.4	39.6	41.1	32.7	28.6	77.8	62.0	32.5	20.0
2 : 00	67.4	55.1	50.0	48.5	39.2	45.0	62.0	72.0	25.7	25.6
2 : 30	55.9	60.0	50.7	50.6	39.4	44.4	37.7	43.4	23.0	35.1
3 : 00	57.4	56.6	32.2	34.5	53.6	45.0	43.7	54.7	38.0	32.5
3 : 30	79.7	64.9	66.5	42.8	51.4	45.0	73.8	63.1	25.7	25.7
4 : 00	60.0	57.1	49.2	49.3	55.3	49.4	50.3	41.8	27.4	28.6
4 : 30	51.4	44.7	44.3	50.7	38.4	36.0	40.6	44.2	32.2	32.7
5 : 00	40.0	42.5	48.5	49.8	44.1	45.0	53.4	48.4	34.8	34.8
5 : 30	49.8	45.0	50.5	43.5	45.0	51.4	37.9	50.2	32.0	32.0
6 : 00	51.4	59.4	42.6	39.1	39.6	45.0	37.9	35.0	38.2	31.9
6 : 30	45.0	56.2	25.5	34.5	43.1	36.0	42.0	57.2	30.0	35.0
7 : 00	35.3	42.3	27.7	26.7	45.0	45.0	24.9	24.0	23.5	27.7
7 : 30	37.9	18.9	25.8	35.0	29.2	25.7	32.5	39.0	34.3	30.0
8 : 00	35.0	14.4	23.0	23.9	45.0	36.0	34.3	44.8	30.0	24.8
8 : 30	39.5	15.0	20.5	25.5	48.5	38.7	34.2	43.6	24.0	29.8
9 : 00	35.6	55.3	18.6	17.1	40.0	42.9	39.9	40.0	30.0	35.1
9 : 30	39.3	17.8	23.5	24.4	43.3	45.0	34.0	45.0	26.8	34.3
10 : 00	48.7	36.0	24.6	20.9	23.7	38.3	36.6	35.2	27.8	27.3
A V E	49.2	44.7	30.1	29.7	35.0	32.9	38.3	40.9	30.7	29.3

Notes 「IN」...Inbound(for Bangkok) 「OUT」...Outbound

3.3 Estimation of the traffic volume in roadways that were not surveyed

3.3.1 Estimation of daily traffic volume

The daytime traffic volume of roadways not subject to monitoring was estimated by applying those described in “BMRT, 1984;Average Daily Traffic”. However there were some roadways whose traffic volumes did not allow such approximation and thus required extrapolation based on known traffic volumes of roadways interlinked. The estimation method is shown in Table 3-4.

3.3.2 Estimation of traffic volume ratios by time period and by vehicle type

The traffic volume ratio of the roadways not surveyed were assumed to be the same as those of roadways in the same links and in nearly equal road width that were surveyed. The names of roadway assumed are shown in Table 3-4. The traffic volume of (4) Others was monitored jointly about LPG cars (Taxi) and motorcycles. Thus to figure out the ratio of both vehicles, the data (ratio) reported by “JICA, 1986; Study on road improvement, rehabilitation and traffic safety in Bangkok” were reviewed and the ratio of taxi to motorcycle was determined to be 36 by 64, corresponding to the observation within Bangkok city limit.

3.3.3 Drive speed estimation

The drive speed of traffic not surveyed was thought same as that of roadways in same link and in similar width that were surveyed. However there were some roads that did not allow this approach and thus drive speed in such roads was assumed unanimously 40 km/hr for those with good surface and 30 km/hr for ones poorly surfaced. As for speedways, the speed was assumed to be 80 km/hr, the speed limit. The Table 3-4 lists the drive speed of motorways applied.

3.4 Determination of emission factors

3.4.1 NO_x emission factor

The NO_x emission volume from driving car varies depending upon various traveling conditions such as vehicle type, speed, manufacturing age, and even car manufacturer. In accordance, NO_x emission factor has to be determined through drive patterning test involving combined effects of the extent and frequency of acceleration, deceleration, and constant navigation. Once drive pattern established, the test run on Chassis-dynamometer will allow the measurement of NO_x emission volume. However the cost and time incurred forbid such drive patterning and Chassis-dynamometer test. Thus referenced for emission factor determination are data reported by Ministry of Construction, Japan set for six types of vehicles and with respect to varying drive speeds. Since the emission control is not practiced in Thailand, the factors applied are those of non-regulated cars in Japan before 1973 as shown in Table 3-5.

Table 3-4 Summary of traffic flow volume

Position	Kind of Road	Route No.	Link No.	Name of route	Daily traffic volume for each vehicle types						Average Speed (km/h)	Estimated method of daily traffic flow volume	Applied ratio for each vehicle types and time	Applied speed
					Diesel		Gasoline	LPG	Motercycle	Total				
					LV	HV								
(1)	2	1	1	FIRST STAGE EXPRESSWAY	2975	982	8721	773	5	13456	80	It is estimated by 「DRAFT FINAL REPORT」.		
(2)	3	3	2	SUKHUMVIT RD.	16386	13314	22991	8728	15517	76936	47	T-1(MS-1) is applied.	T-1(MS-1)	T-1(MS-1)
(3)	3	3	3	〃	16386	13314	22991	8728	15517	76936	* 47		*T-1(MS-1)	*T-1(MS-1)
(4)	3	3	4	〃	10009	8133	14043	5332	9478	46995	47	「BMRT 1984-ADT」 is applied.	T-1(MS-1)	T-1(MS-1)
(5)	3	3	5	〃	2587	2102	3629	1378	2450	12146	47	④−⑪ (46995 - 34849)	T-1(MS-1)	T-1(MS-1)
(6)	3	3	6	〃	8535	2623	5061	4673	8308	29200	40	⑤+⑫ (17054 + 12146)	MS-4-2	
(7)	3	34	7	BANGNA-TRAT HWY.	9692	11158	8814	793	1410	31867	* 65		* MS-5	* MS-5
(8)	3	34	8	〃	6221	7162	5658	509	905	20455	65	「BMRT 1984-ADT」 is applied.	MS-5	MS-5
(9)	3	303	9	SUKSAWAT RD.	13186	12280	12839	6269	11145	55719	* 34		* T-3	* T-3
(10)	6	3113	10	PUCHAO SAMING PHLAI RD.	9129	7848	5307	3547	6306	32137	* 30		* T-2	* T-2
(11)	6	3115	11		10358	6593	6527	4094	7277	34849	* 45		* MS-4-1	* MS-4-1
(12)	6	3115	12		4935	1532	2956	2729	4852	17054	* 56		* MS-4-2	* MS-4-2
(13)	6	3116	13	PHUTTHARAKSA RD.	1527	706	1163	501	890	4787	30	「BMRT 1984-ADT」 is applied.	MS-4-2	
(14)	6	3117	14		474	219	361	156	277	1487	30	「BMRT 1984-ADT」 is applied.	MS-4-2	
(15)	6	3256	15		1160	536	883	380	677	3636	30	「BMRT 1984-ADT」 is applied.	T-5	
(16)	6	3268	16	THEPHARAK RD.	7739	3578	5896	2539	4515	24267	* 30		* T-5	* T-5
(17)	6	3344	17		3051	1501	3639	793	1409	10393	40	⑱−⑯ (34660 - 24267)	T-4	T-4
(18)	6	3344	18		10176	5007	12135	2643	4699	34660	* 40		* T-4	* T-4
(19)	6	3344	19		10176	5007	12135	2643	4699	34660	40		T-4	T-4
(20)	6	4001	20		5410	6228	4920	443	1410	18411	40	MS5 − ①	MS-5	
(21)	6	4002	21		2705	3114	2460	222	705	9206	40	Half of ⑳	MS-5	
(22)	6	4003	22		2705	3114	2460	222	705	9206	40	Half of ⑳	MS-5	
(23)	6	4004	23	THAIBAN RD.	5289	3367	3333	2090	3716	17795	30	⑪−⑫ (34849 - 17054)	MS-4-1	
(24)	6	4005	24	PARAYA PHAYAP RD.	136	117	79	53	93	478	30	It's assumed 40% of T2's traffic count use ferry.	T-2	T-2
(25)	6	4006	25	NAKHON KHUAN KHAN RD.	1630	1401	948	633	1127	5739	30	It's assumed that ㉔:㉕:㉘=5:60:35 .	T-2	T-2
(26)	6	4007	26		815	701	474	316	564	2870	30	Half of ㉕	T-2	T-2
(27)	6	4008	27		815	701	474	316	564	2870	30	Half of ㉕	T-2	T-2
(28)	6	4009	28	PHETCHAHUNG RD.	951	817	553	369	657	3347	30		T-2	T-2
(29)	6	4010	29		476	408	277	184	329	1674	30	Half of ㉘	T-2	T-2
(30)	6	4011	30		476	408	277	184	329	1674	30	Half of ㉘	T-2	T-2
(31)	6	4012	31		935	804	543	363	646	3291	30	Estimated by T2's traffic count and ferry's count.	T-2	T-2
(32)	6	3109	32	NA XLOM RD.								It is neglected because traffic flow volume is not so much.		
(33)	6	3242	33	SUKSAWAT-SAMUTSAKHON RD.										
(34)	6	9001	34	SOI WATDANSAMRONG										
(35)	6	3268	35	THEPHARAK RD.	4967	2297	3785	1630	2898	15577	30	⑯×⑧+⑦	T-5	T-5

(Note 1) Kind of road
2 : Expressway
3 : National road
6 : Provincial road

(Note 2) 「*」 is observed value.

BMRT; Bangkok Metropolitan Regional Transport Sector Study, Office of the National Economic and Social Development Board.

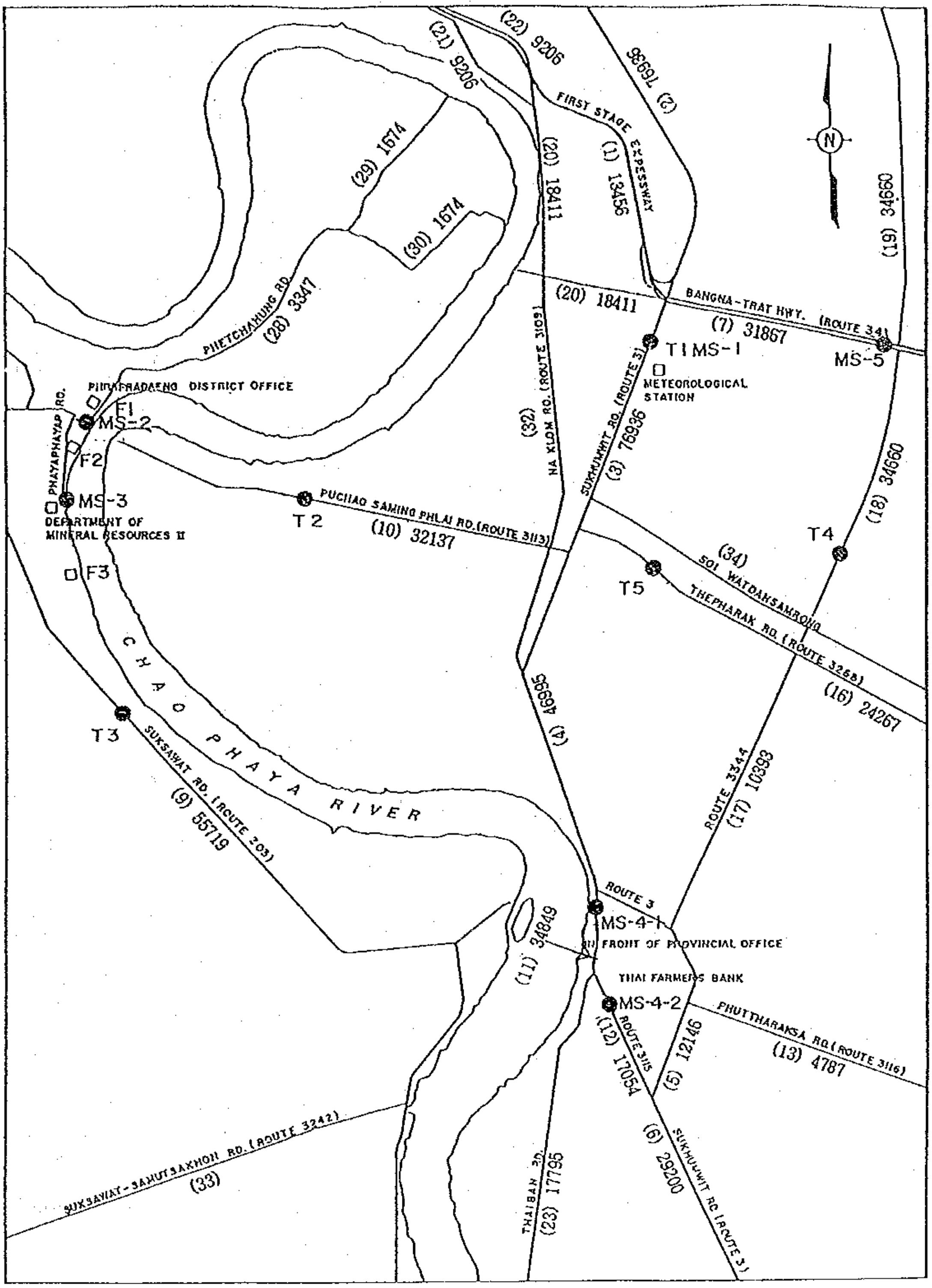


Fig. 3-5 The road map

Table 3-5 NO_x emission factor by Ministry of Construction in Japan
(Non restrictions)

vehicle type	10km/h	20km/h	30km/h	40km/h	50km/h	60km/h	80km/h	100km/h	unit
Passenger car	2.62	2.54	2.82	3.15	3.48	3.75	4.65	4.63	g/km/car
Light cargo vehicle	6.98	5.59	5.26	5.04	4.74	4.27	4.98	8.03	
Heavy duty gasoline vehicle	7.25	6.04	5.92	5.92	5.84	5.60	7.54	8.68	
Diesel vehicle (Direct fuel injection)	2.074	1.654	1.550	1.478	1.381	1.237	1.143	1.864	g/km/ton
Diesel vehicle (Non-direct fuel injection)	1.185	1.019	1.027	1.057	1.075	1.067	1.489	1.933	
Diesel vehicle (Swirl chamber type)	0.889	0.776	0.792	0.825	0.850	0.855	1.148	1.489	

Table 3-5 lists 6 types of vehicles but monitored in Thailand were 5 types of cars. Furthermore, there were a slight difference observed between the definition of vehicle type in Japan and that of Thailand, that required the additional coordination/matching effort.

(1) Gasoline car

The factor of non-regulatory car reported by Ministry of Construction, Japan was applied for this type of car in Thailand as shown by Table 3-6.

(2) LPG driven car

The 10-mode test value of non-regulated LPG car in Japan (average speed 17.7 km, 3.13 g/km. car) was multiplied by emission volume ratio by drive speed described in Table 3-5 for NO_x emission factor estimation of this type. The result is shown in Table 3-6.

(3) Cargo truck

The cargo truck in Thailand was assumed to be 75 pct diesel car and 25 pct gasoline car. The emission factor (g/km, ton, car) of light cargo was approximated from that of diesel car reported by Ministry of Construction, Japan multiplied by the average weight of car, 1.5 ton (Table 3-7) to determine the value for Light weight vehicle in Thailand. The result is shown in Table 3-6.

The emission factor of Heavy vehicle assumed to be of Diesel type and likewise estimated by using the factor of diesel car (g/km, ton, car) reported by Ministry of Construction, Japan multiplied by the average weight of 9.75 ton (Table 3-7). The ratio of engine types was assumed to be 10% : 45% : 45% for direct injection type, non-direct fuel injection type and swirl chamber type respectively and the factor determined corresponds to the weighted average of this combination. The result is shown in Table 3-6.

(4) Motorcycle

The cylinder volume of motorcycle in Thailand is about 125 ml. Thus the factor was assumed to be 1/10 of that of passenger car with the cylinder volume of 1200-1500 ml. The result is also as shown in Table 3-6.

Table 3-6 NO_x emission factor applied for this study

(unit ; g/km/car)

vehicle type	10km/h	20km/h	30km/h	40km/h	50km/h	60km/h	80km/h	100km/h
Light vehicle	2.75	2.27	2.21	2.19	2.14	2.03	2.54	3.68
Heavy vehicle	11.12	9.49	9.49	9.70	9.79	9.64	12.68	16.83
Gasoline	2.62	2.54	2.82	3.15	3.48	3.75	4.65	4.63
LPG	3.21	3.11	3.45	3.85	4.26	4.59	5.69	5.66
Motor cycle	0.26	0.25	0.28	0.32	0.35	0.38	0.47	0.46

Table 3-7 Average weight of trucks

(unit: ton)

Vehicle type		Empty	Loaded	Applied value in this study		
Light vehicle	4 wheel	1	2	1.5		
Heavy vehicle	6 wheel	5	12	8.5	ave. 9.75	6 wheel: 10 wheel=8:2
	10 wheel	8	18~25	14.75		

3.4.2 SO_2 emission factor

The SO_2 emission factor was estimated by the following equation.

$$SO_2 \text{ emission factor (g/km)} = (\text{diesel truck rate}/\text{fuel consumption}(\text{km}/\ell)) \times \text{specific gravity}(\text{kg}/\ell) \times \text{Sulphur content}(\%) \times 64/32 \times 10 \quad \text{(3-1)}$$

Where

Fuel consumption is those described in "Ministry of International Trade and Industry; Manual of Ambient SO_x and NO_x prediction Method in Comprehensive Environmental Assessment, 1982" and Japan Environment Agency; Manual of Total Emission Control for sulphur oxides, 1975", which are 3.3 km/liter for a large truck and 5.9 km/liter for a small truck, specific gravity is thought 0.83 for diesel oil, sulphur content was the mean value (0.46%), which was based on the analysis results of the Diesel oil (0.65%, 0.46%) used in Thailand.

The obtained SO_2 emission factors were listed in Table 3-8.

Table 3-8 SO_2 emission factor applied for this study

vehicle type	Emission factor (g/km/car)
Light vehicle	0.97
Heavy vehicle	2.31

3.5 Calculation of SO_2 and NO_x emission volume

The SO_2 and NO_x emission volumes (per day and per km) were calculated for each of 31 links by multiplying the emission factor (g/km, car) of each car and its traffic volume (car/hr) for 24 hour period and by summing up the products about all vehicle types.

The Table 3-9 shows day average emission volume of NO_x and SO_2 per km and total emission volume in each district of Samut Prakarn in Table 3-10. The source distribution figure of SO_2 and NO_x emission volume from roadway is shown in Fig. 3-6 and Fig. 3-7.
The value is the product of day average of emission volume, total road length in the area and 365 days.
(It would be better to account for an additional 1 km allowance per each link which intersects the provincial borderline.) Hourly variation of emission volume by roadway in whole area is shown in Table 3-11.

Table 3-9 Estimated emission volume per unit length for each route

Link number	Route length (km)		Daily average emission volume per unit length (Nm³/h/km)	
	Whole area	In Samut Prakarn	SO_2	NO_x
1	5.30	0	0.075	1.318
2	4.69	0	0.680	5.773
3	3.31	2.01	0.680	5.773
4	5.28	5.28	0.416	3.527
5	3.77	3.77	0.107	0.911
6	33.88	33.06	0.209	1.638
7	12.07	4.07	0.513	3.580
8	25.38	24.87	0.329	2.298
9	20.27	16.47	0.600	4.270
10	6.40	6.40	0.394	2.509
11	1.10	1.10	0.369	2.585
12	2.06	2.06	0.122	1.013
13	9.69	9.69	0.045	0.311
14	9.48	9.48	0.014	0.097
15	24.27	23.32	0.034	0.236
16	12.27	12.27	0.230	1.577
17	5.80	5.80	0.094	0.735
18	4.59	3.58	0.313	2.450
19	5.01	0	0.313	2.450
20	3.97	0	0.286	1.825
21	2.07	0	0.143	0.912
22	2.02	0	0.143	0.912
23	4.18	4.18	0.188	1.244
24	1.26	1.26	0.006	0.037
25	0.96	0.96	0.070	0.448
26	0.88	0.45	0.035	0.224
27	3.79	2.23	0.035	0.224
28	4.79	4.79	0.041	0.261
29	2.22	2.22	0.020	0.131
30	2.82	2.82	0.020	0.131
31	0.91	0.91	0.040	0.257
35	18.50	18.50	0.148	1.012
Total	242.99	201.55		

Note) 「Whole area」 includes about 1 km outside area from boundary of Samut Prakarn.

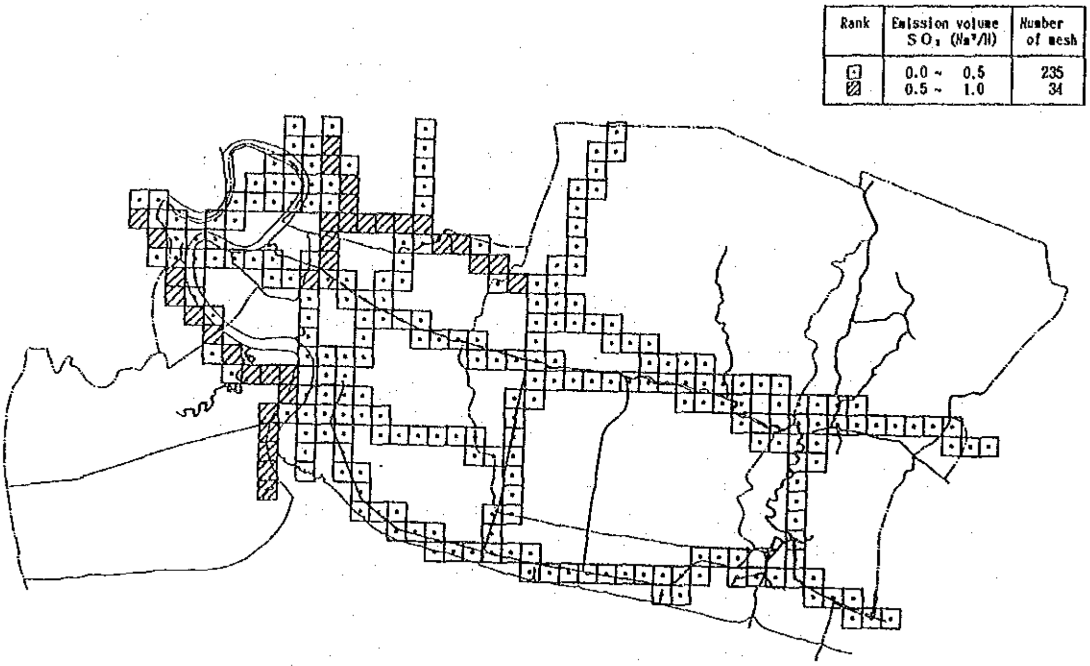
Table 3-10 Estimated emission volume by automobile

County code	Name of county	Emission volume (ton/year)	
		SO_2	NO_x
1	Muang	577.76	3127.45
2	Bang Plee	381.57	1923.84
3	Phra Pradaeng	141.78	686.00
Out of Samut Prakarn		372.96	2074.31
TOTAL		1474.07	7811.60

Table 3-11 Hourly variation of emission volume by road/way in whole area

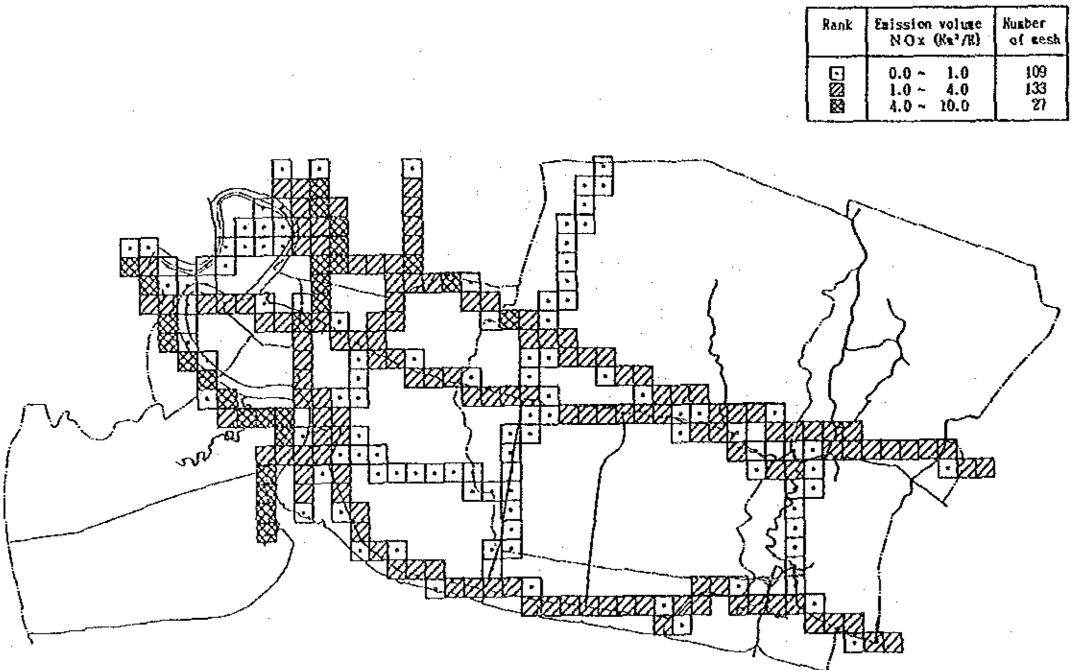
(unit Nm^3/h)

TIME	Emission volume	
	SO_2	NOx
0:00 ~ 1:00	16.9	135.7
1:00 ~ 2:00	13.6	98.7
2:00 ~ 3:00	12.9	88.1
3:00 ~ 4:00	15.1	98.5
4:00 ~ 5:00	21.4	135.1
5:00 ~ 6:00	36.3	229.6
6:00 ~ 7:00	58.9	424.3
7:00 ~ 8:00	63.3	576.9
8:00 ~ 9:00	66.7	528.5
9:00 ~ 10:00	86.7	599.4
10:00 ~ 11:00	102.4	711.0
11:00 ~ 12:00	102.7	738.6
12:00 ~ 13:00	94.6	656.6
13:00 ~ 14:00	90.6	636.0
14:00 ~ 15:00	96.7	671.2
15:00 ~ 16:00	103.1	718.0
16:00 ~ 17:00	88.8	647.6
17:00 ~ 18:00	78.2	649.9
18:00 ~ 19:00	67.9	536.0
19:00 ~ 20:00	58.5	448.8
20:00 ~ 21:00	50.4	378.7
21:00 ~ 22:00	37.4	299.7
22:00 ~ 23:00	28.9	242.3
23:00 ~ 24:00	21.4	171.1
AVE	58.9	434.2



Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
⊡	0.0 ~ 0.5	235
▨	0.5 ~ 1.0	34

Fig. 3-6 The source distribution of SO_2 emission volume from roadway



Rank	Emission volume NO_x (Nm^3/H)	Number of mesh
⊡	0.0 ~ 1.0	109
▨	1.0 ~ 4.0	133
▩	4.0 ~ 10.0	27

Fig. 3-7 The source distribution of NO_x emission volume from roadway

4. Estimation of SO_2 and NO_x emission volume from vessels and ferryboats

4.1 General

Ships up- and down-streaming along Chao Phraya river and ferryboats in Phra Pradaeng provincial part of the river are thought to have some environmental impact and thus the SO_2 and NO_x emission from these sources were estimated.

The SO_2 and NO_x emission volumes from vessels and ferryboats were estimated (as shown in Figure 4-1) by knowing such variables as number of vessels, horse power of their engines, SO_2 and NO_x emission factors.

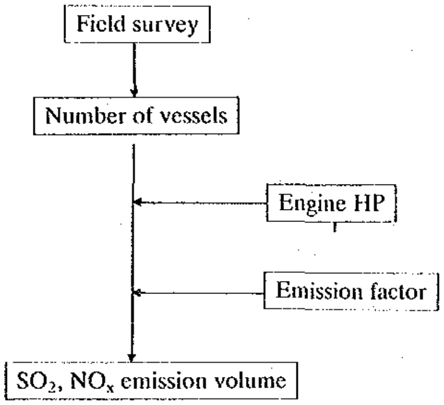


Figure 4-1 Evaluation procedure of SO_2 and NO_x emission volumes from vessels as well as ferryboats

4.1.1 Ships

As aforementioned, the ferrying frequency was checked in the daytime but not at night. Accordingly, the estimation of nighttime frequency had to resort to the information supplied by Thai counterpart.

Same is true for the tonnage variation of ships on sail along Chao Phraya. The density of boats was assumed to be identical everywhere along the Chao Phraya.

The SO_2 as well as NO_x volume was calculated about 37.5 km length of Chao Phraya within the Samut Prakarn district and about the additional 1 km of upstream portion and 5 km off shore of the river mouth to the south. It was assumed that ships with 1,000 tonnage or more used fuel oil, and that 50 percent of ships with less than 1,000 tons used high speed diesel oil and other 50 percent used low speed diesel oil.

The main and backup engine of ships and loading factor of them were assumed to be same as those generally in use in Japan.

4.1.2 Ferryboats

The ferryboats stay at the point on the extrapolated line of Puchao Saming Phrai Road, shuttle across the Chao Phraya carrying some 11-14 cars. There are three routes shown as Fig. 4-2, from the northmost F1 to the South, F2 and F3 and only F1 route is open at midnight. The service is offered on flextime table such that the boat leaves as it is loaded with cargos. The frequency of ferry services at night was not monitored and so it was estimated by using the traffic volume of Puchao Saming Phrai Road.

There are two types of ferryboat, one with 4 engines and the other with two engines suitable for small ferryboat and two engines are run during navigation as well as anchorage. However, the load factor of engines are different between navigation period and anchorage period, thus leads to a difference of SO_2 and NO_x emission volume. The sulphur content of the high speed diesel oil used for ferryboats was thought same as that of high speed diesel oil commonly in use in Thailand. The horse power and navigation speed of them were monitored through field surveys and then the regular calculation methods popularly known in Japan were used to evaluate SO_2 and NO_x emission volumes.

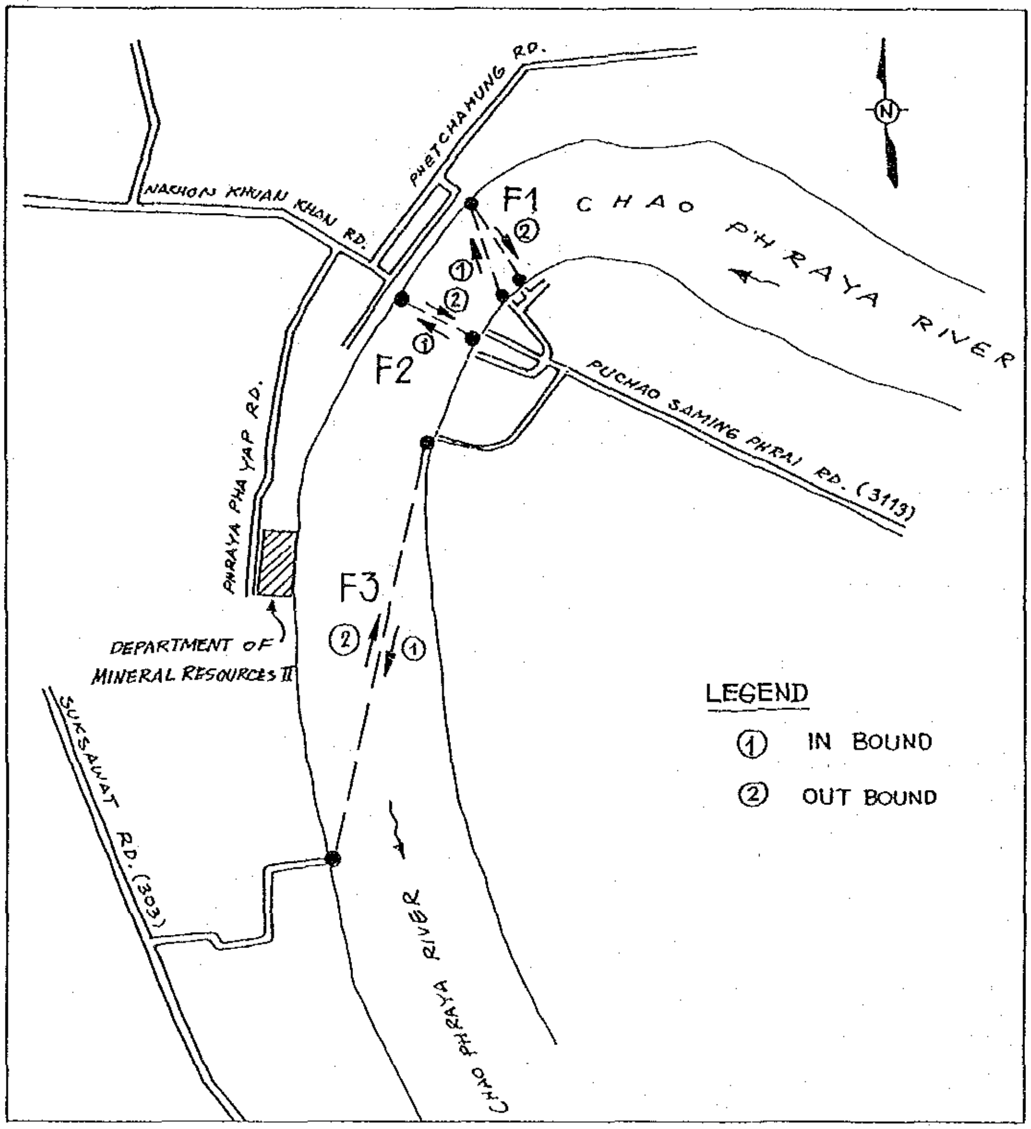


Fig. 4-2 Survey points of vessel and ferryboat navigation

4.2 Field survey

The number of boats and ferries in the river was surveyed twice on January 13th and July 13th, 1988 both during 6:00 through 18:00 time frame. The survey points are shown in Fig. 4-2 and the result of this investigations in Table 4-1 and Table 4-2.

Table 4-1 Vessels up/down streaming observed

Time	1st survey 1988/1/13	3rd survey 1988/7/13
6:00 ~ 7:00	5	1
7:00 ~ 8:00	8	10
8:00 ~ 9:00	10	10
9:00 ~10:00	8	4
10:00 ~11:00	3	12
11:00 ~12:00	13	4
12:00 ~13:00	8	1
13:00 ~14:00	9	1
14:00 ~15:00	10	3
15:00 ~16:00	9	4
16:00 ~17:00	7	13
17:00 ~18:00	6	4
TOTAL	96	67

Table 4-2 Ferryboats shuttling across the river

Time	1st survey 1988/1/13			3rd survey 1988/7/13		
	F1	F2	F3	F1	F2	F3
6:00 ~ 7:00	49	8	6	46	8	15
7:00 ~ 8:00	37	8	16	39	7	19
8:00 ~ 9:00	41	8	18	37	8	19
9:00 ~10:00	52	12	22	46	12	23
10:00 ~11:00	51	14	20	48	12	20
11:00 ~12:00	66	16	20	45	10	22
12:00 ~13:00	58	16	19	48	10	22
13:00 ~14:00	49	11	18	52	15	30
14:00 ~15:00	52	14	21	52	12	34
15:00 ~16:00	53	13	15	51	8	34
16:00 ~17:00	49	12	18	42	12	25
17:00 ~18:00	47	12	11	37	7	19
TOTAL	604	144	204	543	121	282

4.3 Estimation of traffic volume at night

4.3.1 Ships

The traffic volume of boats in Chao Phraya river was monitored during daytime from 6:00 through 18:00 and not at night. Thus it was estimated by means of a material available from Harbour Department, "Communication Section, Harbour Department; Incoming and Outgoing Trips of Vessel in Chao Phraya River, 1988".

The material deals with the traffic volume of all vessels of above 1000 tons passing through the river mouth of Chao Phraya with respect to ship name, nationality, ship's agency and passage time. An example is shown in Table 4-3 about January case of 1988.

Anyhow, the daytime (12 hrs) traffic volume was assumed to be the mean value of two on-site survey results and that of night time was estimated by means of traffic pattern described by the material abovementioned and the daytime survey result. Table 4-4 summarizes the number of ships estimated by time period. The seasonal fluctuation of the traffic was disregarded.

Table 4-3 Vessels incoming and outgoing the river mouth of Chao Phraya (over 1000 tonnage, Jan. 1988)

(unit;ship/hour)

Time	Incomming to BKK Port	Outgoing from BKK Port	Total
0:00 ~ 1:00	11	11	22
1:00 ~ 2:00	12	28	40
2:00 ~ 3:00	11	19	30
3:00 ~ 4:00	8	13	21
4:00 ~ 5:00	16	10	26
5:00 ~ 6:00	38	8	46
6:00 ~ 7:00	49	17	66
7:00 ~ 8:00	34	22	56
8:00 ~ 9:00	26	27	53
9:00 ~10:00	22	32	54
10:00 ~11:00	17	24	41
11:00 ~12:00	12	25	37
12:00 ~13:00	16	12	28
13:00 ~14:00	12	30	42
14:00 ~15:00	32	33	65
15:00 ~16:00	39	37	76
16:00 ~17:00	33	39	72
17:00 ~18:00	46	39	85
18:00 ~19:00	44	48	92
19:00 ~20:00	26	38	64
20:00 ~21:00	37	29	66
21:00 ~22:00	21	24	45
22:00 ~23:00	24	27	51
23:00 ~24:00	32	30	62
TOTAL	618	622	1240

Table 4-4 Vessels up/down streaming the Chao Phraya river

(unit ; ship/hour)

Time	Number of ships
0:00 ~ 1:00	3
1:00 ~ 2:00	5
2:00 ~ 3:00	4
3:00 ~ 4:00	2
4:00 ~ 5:00	3
5:00 ~ 6:00	6
6:00 ~ 7:00	3
7:00 ~ 8:00	9
8:00 ~ 9:00	10
9:00 ~10:00	6
10:00 ~11:00	7.5
11:00 ~12:00	8.5
12:00 ~13:00	4.5
13:00 ~14:00	5
14:00 ~15:00	6.5
15:00 ~16:00	6.5
16:00 ~17:00	10
17:00 ~18:00	5
18:00 ~19:00	11
19:00 ~20:00	8
20:00 ~21:00	8
21:00 ~22:00	5
22:00 ~23:00	6
23:00 ~24:00	7
TOTAL	149.5

4.3.2 Ferryboats

The shuttling frequency of ferries was also determined by averaging the data taken in these two time surveys during 6:00 through 18:00 period. The number of ferries at night (18:00–6:00) was estimated based on the traffic volume of Puchao Saming Phrai road on T-2 link that leads to the pier of ferryboats and the daytime traffic pattern recorded.

The ratios of ferrying services at night (18:00–21:00) via three routes, F1, F2 and F3 were assumed to be 60.4:14.0:25.6 same as those of daytime. However during 21:00 through 6:00 only F1 route is thought in service.

Table 4-5 summarizes the number of ferries in service across the Chao Phraya in both direction for 24 hours period. The monthly fluctuation of traffic volume was disregarded.

Table 4-5 Ferryboats shuttling across Chao Phraya

(unit : ferrys/hour)

Time	Ferry route			
	F 1	F 2	F 3	Total
0:00 ~ 1:00	15	0	0	15
1:00 ~ 2:00	8	0	0	8
2:00 ~ 3:00	6	0	0	6
3:00 ~ 4:00	8	0	0	8
4:00 ~ 5:00	11	0	0	11
5:00 ~ 6:00	19	0	0	19
6:00 ~ 7:00	47.5	8	10.5	66
7:00 ~ 8:00	38	7.5	17.5	63
8:00 ~ 9:00	39	8	18.5	65.5
9:00 ~10:00	49	12	22.5	83.5
10:00 ~11:00	49.5	13	20	82.5
11:00 ~12:00	55.5	13	21	89.5
12:00 ~13:00	53	13	20.5	86.5
13:00 ~14:00	50.5	13	24	87.5
14:00 ~15:00	52	13	27.5	92.5
15:00 ~16:00	52	10.5	24.5	87
16:00 ~17:00	45.5	12	21.5	79
17:00 ~18:00	42	9.5	15	66.5
18:00 ~19:00	39	9	17	65
19:00 ~20:00	41	9	17	67
20:00 ~21:00	30	7	13	50
21:00 ~22:00	29	0	0	29
22:00 ~23:00	28	0	0	28
23:00 ~24:00	24	0	0	24
TOTAL	831.5	157.5	290	1279

4.4 Estimation of SO_2 and NO_x emission volume

Needless to say, the emission volume of SO_2 as well as NO_x varies depending on the type of vessel, displacement tonnage, dead weight tonnage and the status of vessel whether it is on sail or at anchor. Accordingly the emission volume is estimated in terms of those variables.

4.4.1 Vessels

(1) Size variation of vessels

The traffic volume of vessels in Chao Phraya is approximated roughly 150 per day as stated before but they spread widely in vessel size and thus in term of emission volume. The size variation of vessels is assumed as follows.

a) Vessels of less than 1000 and above 1000 gross tonnage

As shown by the aforementioned material published by Harbour Department, the number of vessels above 1000 tonnage during 12 hours period (6:00–18:00) in June 1986 reports 675 in total and 26 per day as averaged over 26 days of survey period.

On the other hand, the number of vessels monitored at site for 12 hours daytime period was 81.5 per day. Thus the ratio of vessels between above 1000 and less than 1000 gross tonnage is calculated as 26:55.5.

b) Breakdown of vessels above 1000 gross tonnage

Harbour Department of Thailand keeps the record of vessels at anchor in Bangkok Harbour with respect to vessel name, harbour entering date, and net cargo tonnage. ("SHIPS MOVEMENT and SHIPS ANCHORED AND ETA, Bangkok Bar" by Harbour Department).

The breakdown of vessels above 1000 gross tonnage is estimated with an assumption that the net cargo (displacement) tonnage is nearly equal to gross tonnage.

Listed in Table 4-6 is the estimated breakdown of vessels at anchor in Bangkok Harbour.

Table 4-6 Breakdown of vessels at anchor in Bangkok Harbour

GT rank (ton)	Ratio (%)
0 ~ 999	68.1
1000 ~ 2999	13.6
3000 ~ 5999	14.2
6000 ~ 9999	3.7
10000 ~	0.4

(2) Estimation of SO_2 and NO_x emission volume

The equation used for estimation are those reported on "MITI, Manual of Ambient SO_2 and NO_x Prediction Method in Comprehensive Environmental Assessment, IPCAJ (1988)".

a) When rating power output×load factor < 1000ps

$$\left.\begin{array}{l}\text{Fuel consumption (kg/Vesssel.hr)} = 0.165 \times \text{rating output} \times \text{load factor} \\ SO_2 \text{ emission vol (kg/vessel.hr)} = \text{fuel consumption (kg/vessel.hr)} \times \text{Sulphur (\%)} \\ \qquad\qquad\qquad\qquad \times (1/100) \times (64/32) \\ NO_x \text{ emission vol } (\text{Nm}^3\text{/vessel.hr}) = 0.00135 \times (\text{rating output} \times \text{load factor})^{1.17} \\ \text{Exhaust gas vol } (\text{Nm}^3\text{/vessel.hr}) = 5.46 \times \text{rating output} \times \text{load factor}\end{array}\right\} \quad (4.1)$$

b) When rating power output×load factor $\geqq$ 1000ps

$$\left.\begin{array}{l}\text{Fuel consumption (kg/vessel.hr)} = 0.15 \times \text{rating output} \times \text{load factor} + 25.24 \\ SO_2 \text{ emission vol (kg/vessel.hr)} = \text{fuel consumption (kg/vessel.hr)} \times \text{Sulphur (\%)} \\ \qquad\qquad\qquad\qquad \times (1/100) \times (64/32) \\ NO_x \text{ emission vol } (\text{Nm}^3\text{/vessel.hr}) = 0.00182 \times (\text{rating output} \times \text{load factor})^{1.12} \\ \text{Exhaust gas vol } (\text{Nm}^3\text{/vessel.hr}) = 5.05 \times \text{rating output} \times \text{load factor} + 490.96\end{array}\right\} \quad (4.2)$$

The rating output and load factor applied in these equations are listed in Table 4-7, same as those presented in the manual.

In regard to sulphur content in fuel, it was assumed that ships with 1,000 tons or greater used fuel oil, so that the mean value (2.5%) of the sulphur content analyses for the four types of fuel oil used in Thailand were applied. In regard to ships displacing less than 1,000 tons, the percentage of ships which use high speed engines and which use low speed engines are about the same, and they use high speed diesel oil and low speed diesel oil, respectively. Therefore, with respect to high speed diesel oil, the mean value (0.56%) of the sulphur content analyses for the two types of diesel oil used in Thailand was used. Regarding low speed diesel oil, the upper limit (1.5%) of the sulphur content standards for marine diesel oil established by the Thai Department of Commerce were used.

The navigation speed of vessels is the average of data monitored at site, 10.8 knot for those of less than 1,000 tonnage and 8 knot for large vessels over 1,000 tonnage. The vessel speed of 8 knot corresponds to the legal limit and is thought reasonable for bulky ones.

The emission factor for vessels of less than 1,000 tonnage is discretely defined for three categories, 0–99 ton, 100–499 ton and 500–999 ton range in Japan. However, the breakdown of vessels in Thailand is not known and so the emission factor is determined with respect to the 250 ton vessel as representative one.

Table 4-7 Horsepower , load factor, sailing speed
and fuel sulphur content by vessel size

GT rank (ton)	Output (HP)		Sulfer con- tents (%)	Load factor		Sai- ling Speed (knot)
	main engine	sub engine		main engine	sub engine	
0 ~ 999	450	40	0.56 1.5	0.85	0.39	10.8
1000 ~ 2999	2,400	131	2.5	0.85	0.39	8
3000 ~ 5999	4,600	232	2.5	0.67	0.39	8
6000 ~ 9999	8,000	337	2.5	0.40	0.39	8
10000 ~	11,825	568	2.5	0.40	0.39	8

4.4.2 Ferryboats

The NO_x and SO_x volume estimation relies on the equation (4-1) as previously shown and is calculated by applying the values listed in Table 4-8.

Table 4-8 Horsepower, load factor, sailing speed
and fuel sulphur content of ferrys

Term		Set up value	Set up base
Number of engines		2 engines	Large ferry has 4 engines. Small ferry has 2 engines. Large and small ferry also normally operate 2 engines.
Output of main engine		F1,F2 225ps F3 200ps	As a result of field survey, it is set up. At F1 and F2 ferry route, average horsepower of 240ps (10ferrys) and 200ps(6ferrys) is 225ps.
Sulfur contents		0.56 %	It is averaged value by sulfur contents of 2 kinds of high speed diesel oil which is consumed in Thailand.
Load factor	Anchoring	0.5	As a result of field survey, it is set up.
	Sailing	1.0	
Anchoring time		2.5 min	As a result of field survey, it is set up.
Sailing speed		3.72 km/h	As a result of field survey, it takes about 5 minutes at a distance of 310 meters. Therefore, sailing speed is 3.72 km/h. Sailing length is F1;350m, F2;310m, F3;1500m. Sailing time is calculated that sailing length devide by sailing speed.

4.5 The summary of SO_2 and NO_x emission estimation for ferryboats and ohter vessels combined

Both NO_x and SO_2 emission volumes are listed for vessels of varying size and ferryboats in Table 4-9 and Table 4-10, respectively. Hourly variation of emission volume by vessels and ferry-boats is shown in Table 4-11. Source distribution figure of SO_2 and NO_x emission volume from vessels and ferryboats is shown in Fig. 4-3 and Fig. 4-4.

Table 4-9 SO_2 and NO_x emission by vessel size

GT rank (ton)	SO_2 (ton/year)			NO_x (ton/year)		
	main engine	sub engine	total	main engine	sub engine	total
0 ～ 999	108.7	4.4	113.1	243.6	5.8	249.4
1000 ～ 2999	373.3	9.5	382.8	428.9	6.2	435.1
3000 ～ 5999	561.9	17.6	579.5	693.6	12.7	706.3
6000 ～ 9999	154.9	6.6	161.5	193.2	5.7	198.9
10000 ～	24.4	1.2	25.6	32.3	1.0	33.3
TOTAL	1223.2	39.3	1262.5	1591.6	31.4	1623.0

Table 4-10 SO_2 and NO_x emission from ferryboats

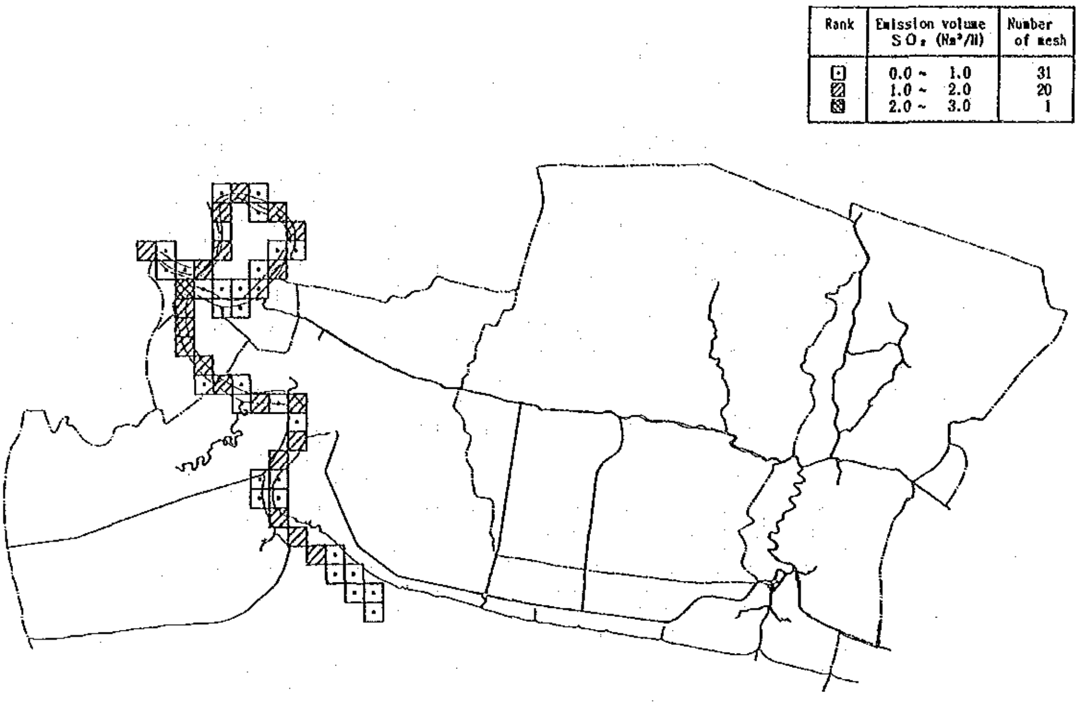
(unit : ton/year)

Ferry route	SO_2 emission volume			NO_x emission volume		
	Anchoring	Sailing	Total	Anchoring	Sailing	Total
F 1	5.26	23.75	29.01	17.61	89.46	107.07
F 2	1.00	3.98	4.98	3.33	15.01	18.34
F 3	1.63	31.55	33.18	5.35	116.50	121.85
Total	7.89	59.28	67.17	26.29	220.97	247.26

Table 4-11 Hourly variation of emission volume by vessels and ferryboats

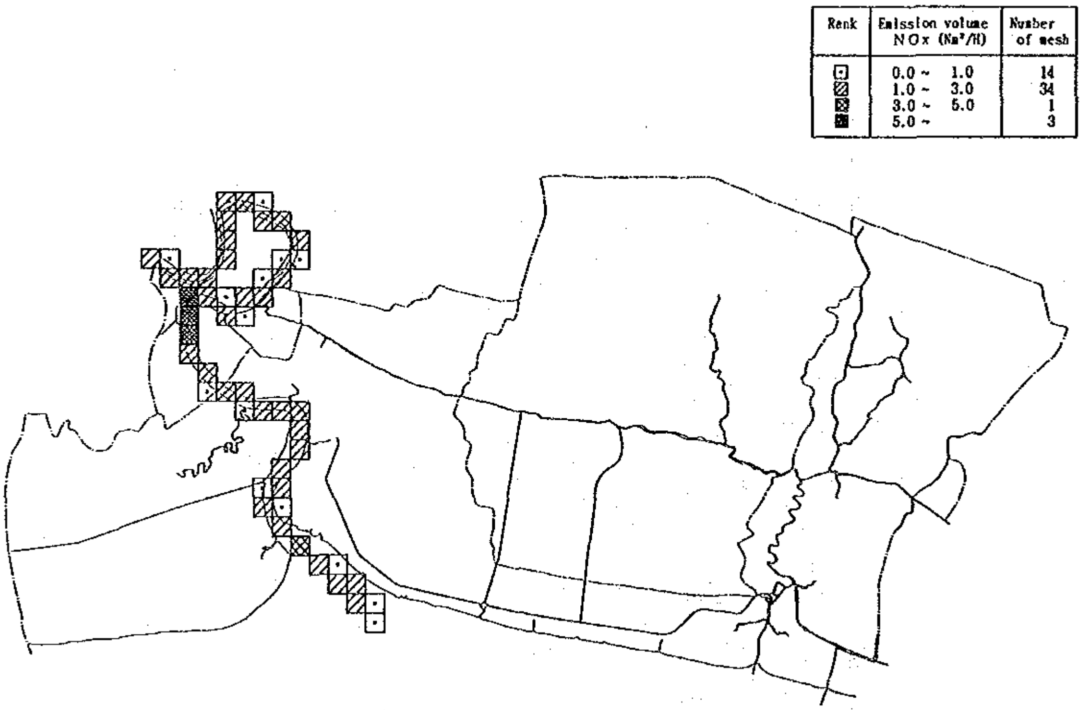
(unit Nm^3/h)

TIME	Vessels		Ferryboats		TOTAL	
	SO_2	NOx	SO_2	NOx	SO_2	NOx
0:00 ～ 1:00	24.3	43.5	0.5	2.6	24.8	46.1
1:00 ～ 2:00	40.5	72.4	0.3	1.4	40.8	73.8
2:00 ～ 3:00	32.4	57.9	0.2	1.0	32.6	58.9
3:00 ～ 4:00	16.2	29.0	0.3	1.4	16.5	30.4
4:00 ～ 5:00	24.3	43.5	0.3	1.9	24.6	45.4
5:00 ～ 6:00	48.6	86.9	0.6	3.3	49.2	90.2
6:00 ～ 7:00	24.3	43.5	3.0	15.3	27.3	58.8
7:00 ～ 8:00	72.9	130.4	3.4	17.5	76.3	147.9
8:00 ～ 9:00	81.0	144.8	3.6	18.3	84.6	163.1
9:00 ～ 10:00	48.6	86.9	4.5	22.9	53.1	109.8
10:00 ～ 11:00	60.7	108.6	4.2	21.7	64.9	130.3
11:00 ～ 12:00	68.8	123.1	4.6	23.3	73.4	146.4
12:00 ～ 13:00	36.4	65.2	4.4	22.6	40.8	87.8
13:00 ～ 14:00	40.5	72.4	4.7	24.2	45.2	96.6
14:00 ～ 15:00	52.6	94.1	5.2	26.4	57.8	120.5
15:00 ～ 16:00	52.6	94.1	4.7	24.3	57.3	118.4
16:00 ～ 17:00	81.0	144.8	4.2	21.7	85.2	166.5
17:00 ～ 18:00	40.5	72.4	3.3	17.1	43.8	89.5
18:00 ～ 19:00	89.1	159.3	3.4	17.6	92.5	176.9
19:00 ～ 20:00	64.8	115.9	3.5	18.0	68.3	133.9
20:00 ～ 21:00	64.8	115.9	2.6	13.5	67.4	129.4
21:00 ～ 22:00	40.5	72.4	0.9	5.0	41.4	77.4
22:00 ～ 23:00	48.6	86.9	0.9	4.8	49.5	91.7
23:00 ～ 24:00	56.7	101.4	0.8	4.1	57.5	105.5
AVE	50.4	90.2	2.7	13.7	53.1	103.9



Rank	Emission volume SO_2 (Nm^3/H)	Number of mesh
⊡	0.0 ~ 1.0	31
▨	1.0 ~ 2.0	20
▩	2.0 ~ 3.0	1

Fig. 4-3 Source distribution of SO_2 emission volume from vessels and ferryboats



Rank	Emission volume NO_x (Nm^3/H)	Number of mesh
⊡	0.0 ~ 1.0	14
▨	1.0 ~ 3.0	34
▩	3.0 ~ 5.0	1
■	5.0 ~	3

Fig. 4-4 Source distribution of NO_x emission volume from vessels and ferryboats

5. SO_2 and NO_x emission volume emitted from the total area of Samut Prakarn

The total emission volumes, as summed up for those coming from all sources such as factories, automobiles, boats and ferries, are as shown in Table 5-1 and these pollutant emissions by each mesh segment area in Figure 5-1 and Figure 5-2.

As shown by them, the total SO_2 emission from this specified are break into 86.7% from the factories (18,330 tons/y), 7.0% from automobiles (1,474 tons/y) and 6.3 % from vessels and ferries (1,764 tons/y). Samely the total NO_x volume is shared by factories 47.7% (8,820 tons/y), by automobiles 42.2% (7,812 tons/y) and by vessels and ferries 10.1% (1,870 tons/y).

Table 5-1 Summary of emission volume in 1988

Name of source		Type of source	SO_2 emission volume (ton/year)	NO_x emission volume (ton/year)
Stationary sources	Questionnaire return	point	13649	8108
	Questionnaire nothing	area	4681	712
	Sub total		18330	8820
Road way		line	1474	7812
Vessels and Ferryboats	Vessels (sailing)	point	1263	1623
	Ferryboats (anchoring)	point	8	26
	Ferryboats (sailing)	point	59	221
	Sub total		1330	1870
TOTAL			21134	18502

Rank	Emission volume SO_x (Nm^3/H)	Number of mesh
⊡	0.0 ~ 1.0	364
▨	1.0 ~ 10.0	90
▩	10.0 ~ 100.0	18
■	100.0 ~	1

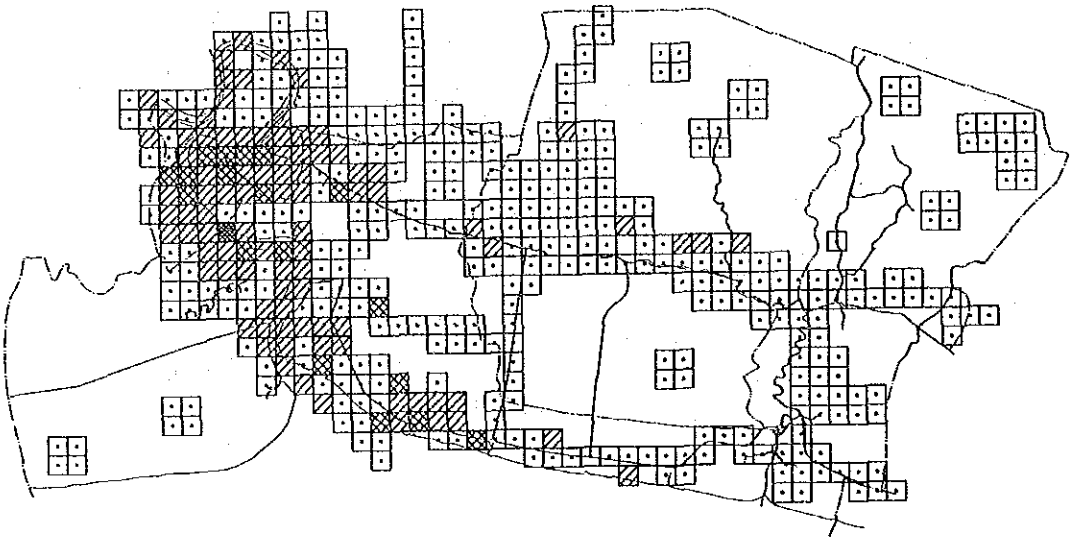


Fig. 5-1 Source distribution of SO_2 emission volume from all sources

Rank	Emission volume NOx (Nm^3/H)	Number of mesh
⊡	0.0 ~ 1.0	256
▨	1.0 ~ 10.0	208
▩	10.0 ~ 100.0	2
■	100.0 ~	1

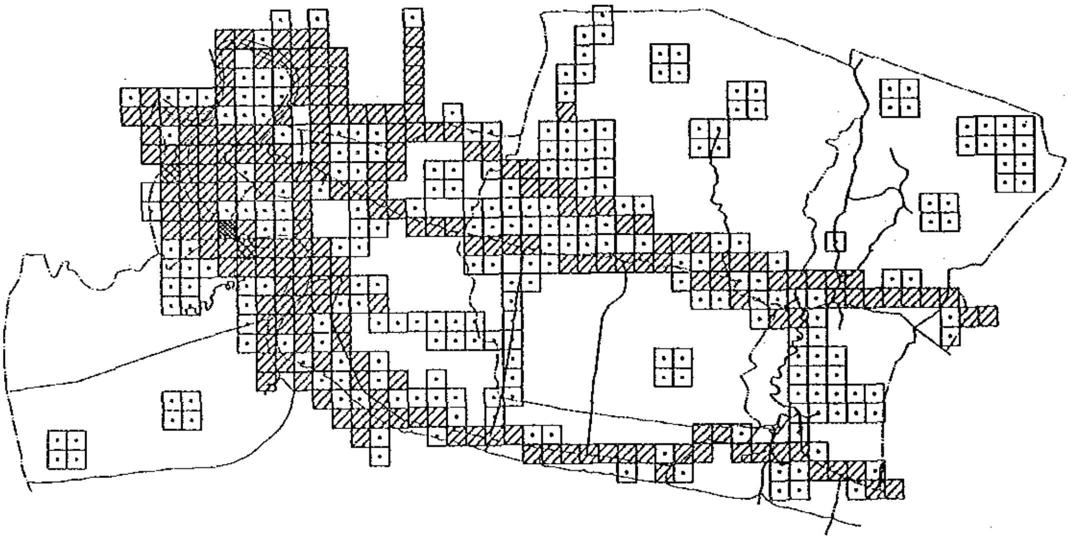


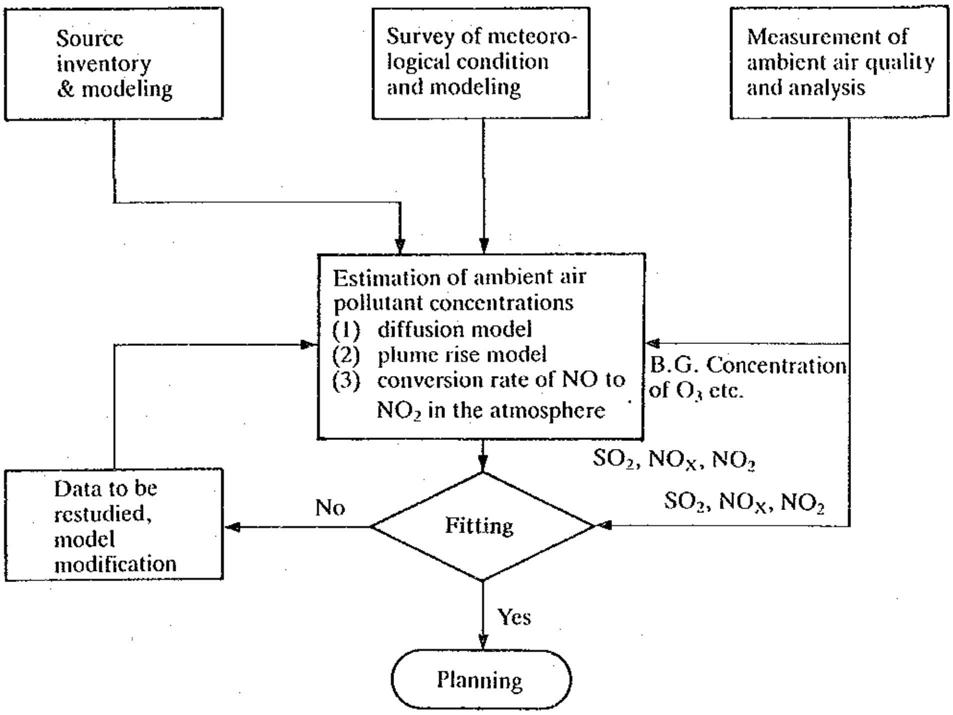
Fig. 5-2 Source distribution of NO_x emission volume from all sources

PART V ANALYTICAL STUDY ON CURRENT AMBIENT POLLUTANT CONCENTRATIONS BY USING ATMOSPHERIC SIMULATION MODELS

The atmospheric pollutant (SO_2 and NO_2) concentrations across the Samut Prakarn district is estimated by using simulation models to represent atmospheric diffusion status of the area and the obtained values are subject to analytical studies, comparison with standards and estimation of contribution of each source to atmospheric concentration. As for the particulate matter, the samples collected at the site are analysed and by knowing the chemistry of such dust samples the survey team estimated the contribution of each source by means of chemical mass balance method.

1. Atmospheric Simulation Models for Evaluation of Ambient SO_2 and NO_2 Concentrations

Using such data as SO_2 and NO_x emission volume from factories, roadways and vessels, meteorological and ambient air pollutant concentration data measured at monitoring stations, atmospheric pollutant concentrations to represent the whole area of Samut Prakarn province as of 1988 are calculated by using the air diffusion model as shown in the following flowchart.



Flow Chart of Simulation Process for SO_2, NO_x and NO_2

1.1 Simulation Methods

1.1.1 Physical and Numerical Simulation Models

Up until now, several atmospheric diffusion simulation methods have been proposed. These are roughly classified into two groups, the physical laboratory models such as wind tunnel and water channel, and the mathematical models. The classification of those models is given in Table 1-1.

(1) Air Tracer Experiment and Laboratory Model Simulation

The air tracer experiment is a direct method of diffusion study, being comprised of such steps as the release of air tracer substances from a site where plant construction is planned, sampling of the diluted gas and analysis of such sample gas. As for the air tracer, SF_6 (Sulfur Hexa Fluoride) is used because the substance is non-toxic for both humans and plants. The air tracer substance also should be easily detectable by a chemical method, even in trace amounts. By analyzing obtained diffusion results together with the meteorological data, one can evaluate detail characterisitcs of atmospheric diffusion behavior at the construction site.

As for the diffusion over complex terrain or abnormal diffusion problems near stacks involving down-wash or down-draft, a fluid simulation model such as a wind tunnel or a water channel is often employed since the mathematical modelling is prohibitive. In fluid model simulation, the tracer substance is emitted from model stacks and its diffusion is examined visually or by using measuring instruments.

Table 1-1 Classification of Simulation Models of Air Pollution

- * Air tracer experiment
- * Fluid models
    - Wind tunnel experiment
    - Water channel experiment
- * Mathematical simulation model
    - Numerical model
        - Finite element method
        - Finite difference method
        - etc.
    - Analytical model
        - Plume model
        - Puff model
        - etc.
    - Empirical Model

(2) Mathematical Models

Fluid simulation model requires special facilities like a wind tunnel or a water channel and it is not adequate to obtain forecasts of changing meteorological or source conditions. However, mathematical models to represent the diffusion mechanism have flexibility and versatility to evaluate the atmospheric concentrations for changing meteorological and pollutant sourcing conditions. Presently available mathematical models, however, have application limits and difficulties in applying them for special diffusion problems involving complex terrain, buildings, and meteorological conditions. Therefore, we have to select proper models each time depending on the nature of the problems, e.g. a mathematical model for a long term diffusion problem or a fluid model for a terrain affected diffusion.

The pollutants released into the atmosphere are transported and dispersed by wind. If we can assume that the diffusion of pollutant is proportional to the gradient of concentration, then the diffusion is expressed by the following equation. Almost all of the mathematical models adopt this diffusion equation.

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z}$$
$$= \frac{\partial}{\partial x}(Kx\frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(Ky\frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(Kz\frac{\partial C}{\partial z}) + Q \quad \text{..........................} \quad (1\text{-}1)$$

where;

Kx: eddy-diffusion coefficient in the x-direction (m^2/sec)
Ky: eddy-diffusion coefficient in the y-direction (m^2/sec)
Kz: eddy-diffusion coefficient in the z-direction (m^2/sec)
Q: Source intensity (unit/sec)

1) Numerical model

Numerical models solve the diffusion equation by the finite difference method or the finite element method using a computer. They are thought effective for unstable conditions and also for complex meteorological conditions. But they often require long computation time and expenses. It is not recommended for use in the prediction of the annual average concentrations for a simulation of long term prediction of average concentration under changing meteorological conditions that incur considerable expense. In accordance, numerical methods are thought suitable for roadway diffusion problems to which analytical models can not be applied or for diffusion of chemically active pollutants such as hydrocarbon and oxidants.

2) Analytical models

An analytical model is one in which an analytical solution to the diffusion equation is used to estimate concentration of pollutants. Many solutions have been propsed for different boundary and flow conditions. Among them, the Gaussian plume and Gaussian puff models are most commonly in use.

① Gaussian plume model

The Gaussian plume model is the solution of the Fickian type diffusion equation in which pollutants are emitted continuously at a constant flow rate. Then the pollutant disperses as shown by a plume and in concentration whose lateral and vertical profiles are expressed by the Gaussian distributions (Fig. 1-1).

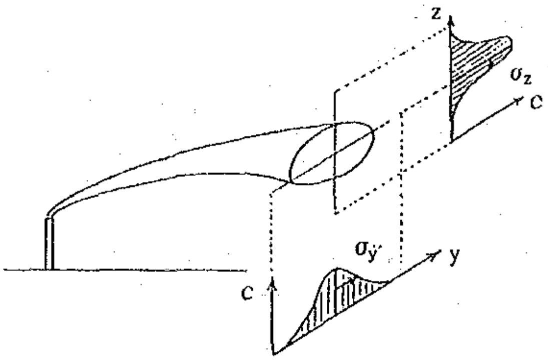


Fig. 1-1 Schematic Representation of the Gaussian Plume Model

In the equation, the ground point where the source stack stands is the origin (0,0,0), the x-axis is the downwind direction and the y-axis is taken normal to the x-axis. The z-axis is the vertical direction. Therefore, the coordinate of the source point is (0,0,He), where He is the effective plume height, i.e., the sum of the stack height and plume rise. (Fig. 1-2).

The distribution of flue gas concentration along y-axis on the plane vertical to the central axis of the plume often complies with the Gaussian distribution profile, in which the concentration maximum lies right on the center axis and then decreases symmetrically as the distance from the axis gets larger. The standard deviation of flue gas concentration, σ is used to indicate the spread of its distribution.

The vertical distribution along the z-axis on the same plane seems to show a somewhat different profile. Neverthless, it can be also approximated by a Gaussian model.

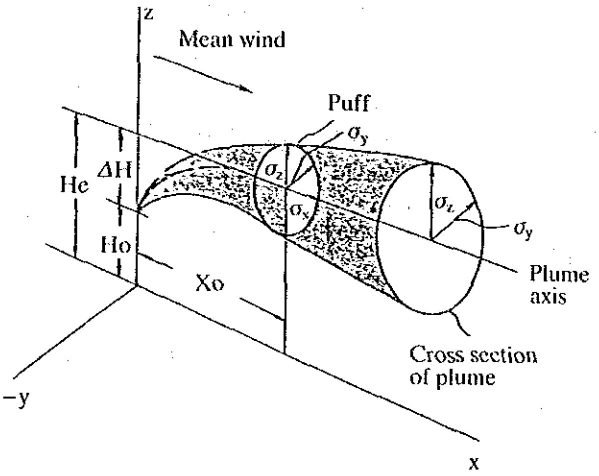


Fig. 1-2 Coordinates of Smoke Plume and Puff Diffusion Model

The concentration of a pollutant at a point (x, y, z) is given by

$$C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp(-\frac{y^2}{2\sigma_y^2})\left\{\exp(-\frac{(z-He)^2}{2\sigma_z^2}) + \exp(-\frac{(z+He)^2}{2\sigma_z^2})\right\}\ldots(1\text{-}2)$$

where symbols are as follows:

C (x, y, z): Concentration of a pollutant at a point (x, y, z)

x, y, z: Longitudinal, lateral and vertical coordinate of the point. x and y are measured from the source point and the lateral distance from the axis which passes through the source point, respectively. z is the vertical height of the point above the ground.

Q: Emission rate of the pollutant (m^3/s)

u: Wind velocity (m/s)

He: Effective stack height (m)

σ_y: Plume width in lateral direction (m)

σ_z: Vertical plume width (m)

The plume equation (1-2) requires the following conditions in its application.

i) The pollutant should be gaseous or particles which are small enough to make falling velocity negligible.

ii) The pollutants should be inert gases or non-reactive substances which will not cause chemical reactions.

iii) The pollutants cannot be absorbed or released through the ground surface.

iv) Wind velocity and direction should be steady in space and time.

v) The diffusion coefficient is assumed to be identical across the whole target space.

vi) Emission rate of pollutant is constant and does not change with time.

vii) The diffusion in the x direction can be negligible as compared with the effect of wind.

These assumptions are not always necessary conditions for us to solve the equation (1-1). In fact, the solution is obtainable without some of above constraints but it takes often a very complex form. An example is the Walter's equation1) upheld when the wind velocity and diffusion coefficient change along the height from the ground. If diffusion coefficients Ky, Kz are assumed uniform across the space, one can get the plume equation (1-2) of the Gaussian type even when Ky and Kz vary with time.

According to the statistical theory by Taylor2), the following equation (1-3) is upheld between diffusion coefficient K and diffusion width σ for 2-3 hours from the start of diffusion when the atmospheric turbulency is steady and uniform.

$$\sigma^2=2Kt \quad\ldots\ldots\ldots\ldots\ldots\ldots \quad (1\text{-}3)$$

where; t is the travelling time

The vertical plume diffusion width is strongly influenced by the atmospheric stability. In the unstable atmoshperic condition where fluctuation of wind is prominent in the vertical direction, the plume disperses and σ_z gets larger quickly. On the other hand, in a stable case, (this is the case that air temperature increases as the position gets higher and inversion takes place) turbulence is suppressed and σ_z gets smaller. The plume width depends strongly on the turbulence intensity and several formulae to estimate the plume width in terms of turbulence intensity have been proposed. But from a practical point of view, turbulence data to cover long term period are not easily obtainable. Thus, Pasquill's method which gives vertical and lateral plume widths for each stability category (A~F) in graphic form is broadly applied. Pasquill's stability classification is described in Table III-1-5.

Pasquill's chart for σ_y and σ_z are given in Fig. 1-3. The plume widths are estimated from the figures at any downstream poin of between 0.1 to 100 km and with respect to each stability class.

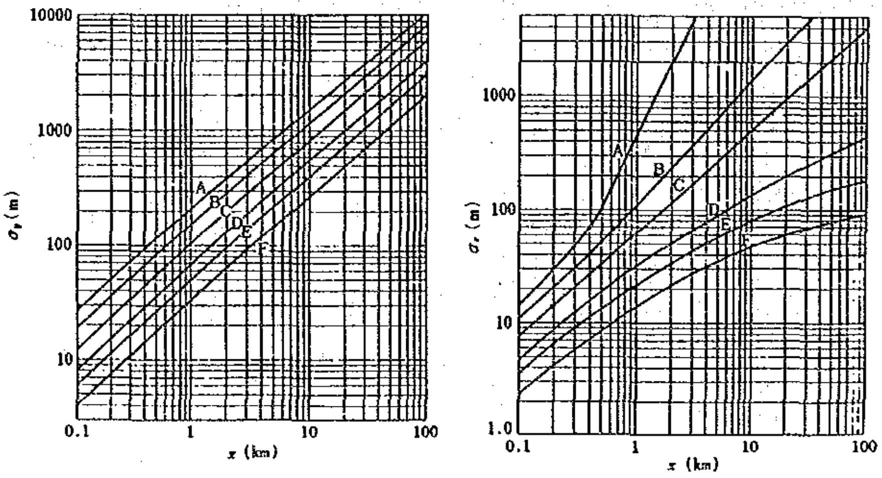


Fig. 1-3 Plume Width by Pasquill-Gifford

This diagram shows the spread of the diffused smoke plume[3] to the downstream direction at six typical atmospheric stabilities that were first empirically developed based on experiments done with prairie grass and then modified by Gifford.[4] Turner reported the diagram in his text dealing with air diffusion as the Pasquill-Gifford diagram.[5] The diffused plume width was originally measured about a smoke source positioned at 0.5 m high on a flat grassland for the period of 10 minutes (later reported by his paper is 3 minutes[6]). Neverthless, the diagram is effectively applied to the distance range of 100 m to 1 km or to outside of this range by extrapolation. In any case, the Pasquill-Gifford diagram is popularly in use because of its simplicity.

The diffusion width of the plume in the open air is nearly identical both in the vertical and horizontal directions in a few minutes but as time becomes longer than half an hour (or an hour), the horizontal plume width becomes larger than that of the vertical width due to the nature of air characteristics that the scale of eddy currents are more pronounced in the horizontal than in the vertical direction. The eddy current in the horizontal direction works to add to the vector of plume diffusion as time passes by while the plume width σ_z shows minor change vertically as shown in Fig. 1-4 and the concentration dilutes quickly.

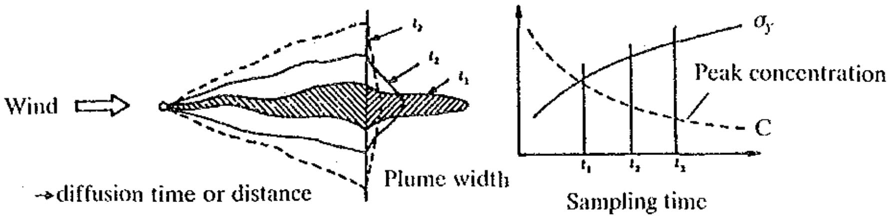


Fig. 1-4 Horizontal Plume Width for Different Sampling Time

The horizontal diffusion width varies with observation time and generally increases proportionally to the power of the observation time ratio (t_1/t_2). Thus by applying $\sigma_y/x \approx \sigma_A$, the equation (1-4) is upheld.

$$\sigma_{y1}/\sigma_{y2}=\sigma_{A1}/\sigma_{A2}=(t_1/t_2)^m \quad \text{(1-4)}$$

where;

σ_{y1}: diffusion width at observation time t_1

σ_{A1}: standard deviations of plume spread angle at observation time t_1

m: power coefficient

The value of the power coefficient is reported to be 0.2~0.3 by Hanna[6]. According to a short time model[7] developed by the Texas Air Control Committee, the diffusion width $\sigma_{y,t}$ at observation time t, is calculated by knowing the diffusion width σ_y, t_0 ($t_0=10$ min) as follows: $\sigma_{y,t}=\sigma_{y,}\ t_0/(t_0/t)^m$

The value m is a constant given by Table (1-2) for each atmospheric stability group. P-G diagram shows the relationship between σ_y and x for varying atmospheric stability, in which the D group corresponds to a neutral point and the equation $\sigma_y=0.147x^{0.89}$ is upheld for approximation of the σ_y value (within a 3 minute time range). The equation $\sigma_y=0.31\cdot x^{0.89}$ is obtained when the equation $\sigma_y=0.147x^{0.89}$ is corrected to the hourly equivalent, by using average power coefficient 0.25.

Table 1-2 Time Correction Factor m of Horizontal Plume Diffusion Width

Atmospheric stability group	A	B	C	D	E	F
m	0.675	0.55	0.425	0.30	0.175	0.175

② Gaussian puff model

The basic idea of the puff model is to express a continuous plume by a series of discrete puffs as illustrated in Fig. 1-5. In the Gaussian puff model, the concentration profiles take Gaussian form along the x, y and z axes (Fig. 1-2).

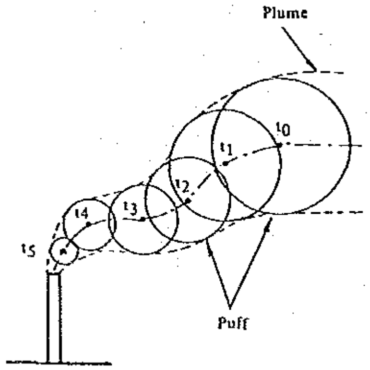


Fig. 1-5 Schematic Representation of Gaussian Puff Model

The concentration profile at time t after the start of emission takes a Gaussian form (1-5) as the solution to the equation (1-1).

$$C = \frac{Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\exp\left\{-\frac{(x-ut)^2}{2\sigma_x^2}-\frac{(y-vt)^2}{2\sigma_y^2}-\frac{(z-wt)^2}{2\sigma_z^2}\right\} \cdots\cdots\cdots\cdots \quad (1\text{-}5)$$

The equation (1-5) can be expressed as equation (1-6) when the position of the source is assumed at He and the wind blows steadily in the X direction. Both equations (1-5) and (1-6) are thus called the "puff model" for calculation of concentrations.

$$C(x, y, z, t) = \frac{Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\exp\left[-\frac{(x-ut)^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}\right]\cdot \left\{\exp\left[-\frac{(z-He)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(z+He)^2}{2\sigma_z^2}\right]\right\} \cdots\cdots\cdots\cdots \quad (1\text{-}6)$$

Equation 1-6 expresses the concentration by a puff and the actual concentration from a continuously emitting source is calculated by summing up concentrations of all puffs. Accordingly, the equation is

$$C = \int_0^\infty \frac{Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left\{-\frac{(x-ut)^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}\right\}$$

$$\left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right]dt \quad \cdots\cdots \quad (1\text{-}7)$$

The puff models do not require the previously mentioned restrictive conditions (iv), (vi) and (vii) to be applied and are thought suitable for changing the intensity of emission and wind velocity because the concentration profile is estimable by numerical integration. However, they normally involve a considerable volume of computation, though the puff models do not neglect the diffusion to the downstream direction unlike th plume model. In any case, when the same conditions of diffusion are assumed, both equations of the puff model and the plume model give a similar calculation result at wind velocity above 1 m/s. When the wind velocity maintains zero or is negligibly small, the equation (1-8) is derived from the equation (1-7) by introducing $u=0$ and further by assuming the diffusion widths σ_x, σ_y, and σ_z being proportional to the lapse of time ($\sigma_x=\sigma_y=\alpha t$; $\sigma_z=\gamma t$), the equation (1-8) is modified into equation (1-9).

$$C = \int_0^\infty \frac{Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \cdot\exp\left(-\frac{x^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}\right)\cdot \left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\} + \exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right]dt \quad \cdots\cdots \quad (1\text{-}8)$$

$$C(R,Z) = \frac{Q}{(2\pi)^{3/2}\gamma}\left\{\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(He-Z)^2}+\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(He+Z)^2}\right\} \quad \cdots\cdots \quad (1\text{-}9)$$

where;

R is the horizontal distance between the source and calculation point (m)

$R^2=x^2+y^2$

In calculation of atmospheric concentrations by the puff model when the wind velocity maintains nearly zero, the diffusion widths σ_x, σ_y and σ_z of the smoke have to be expressed as a function of the lapse of time (t) as previously explained. The Turner diagram[8)] shown below (Fig. 1-6) is often used to approximate such diffusion widths with some modification to be mentioned later. The Turner diagram is primarily derived from the Pasquill-Gifford diagram while the wind velocity is kept at about 5 m/s and thus it is thought inappropriate to apply the diagram directly to the zero wind case.

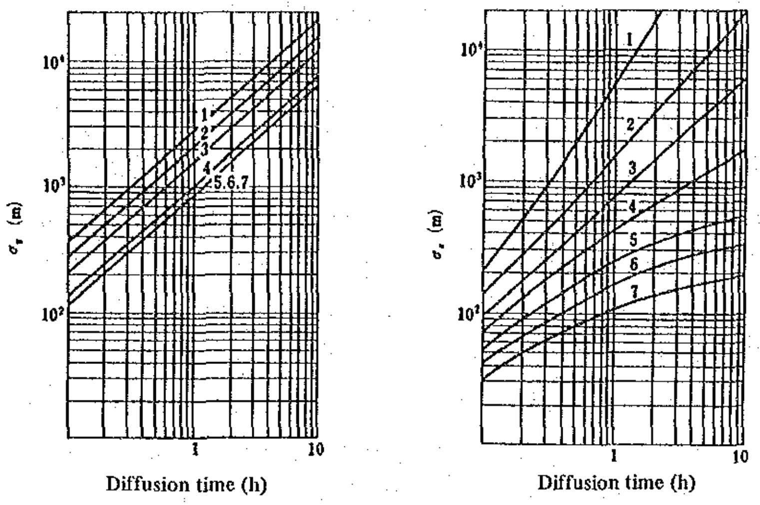


Fig. 1-6 The Diffusion Width by Turner

1.1.2 Methods for Calculation of Effective Stack Height

The smoke emitted from the stack mouth reaches a certain height as shown in Fig. (1-7) due to the combined effect of buoyancy coming from the temperature difference between smoke and surrounding air and the upward force vector of smoke itself. The height is called the effective stack height (He) and is the sum of the stack height (Ho) and plume rise (ΔH).

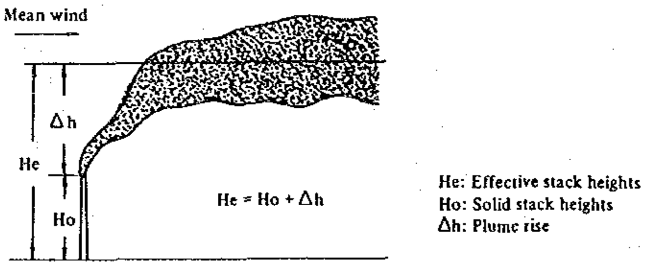


Fig. 1-7 The Relation between Plume Rise ΔH and Effective Plume Height

In the calculation of plume and puff equations, the pollutant is conventionally assumed to be emitted at the effective stack height. For the plume rise, many formulae, theoretical, empirical or semi emipirical, have been proposed. Table 1-3 shows the representative plume rise equations together with their application conditions.

There are a number of equations proposed to calculate the effective stack height that can be grouped into two types, one of empirical origin and the other theoretically derived. Table 1-3 lists such equations with application specifics. The value (Δh) varies from equation to equation and sometimes gives the difference as large as two times of one to the other at zero wind velocity but the equation by CONCAWE is reported recently as one which offers the best agreement between calculated and observed values.[9]

Table 1-3 Plume Rise Equation and its Application Range

	Year	Plum rise equation Q_H (kcal/sec), U (m/sec), H_S (m), ΔT (°K) T_a (°K), V (m/sec), Q_v (m³/sec), $\Delta\theta/\Delta z$ (°K/m)	Theoretical or empirical	Stability condition	Basic conditions of used data			
					Q_H *(kcal/sec)*	H_S *(m)*	U *(m/sec)*	V *(m/sec)*
1 Bosanquet 1st formula	1950	$\Delta h = \Delta h_m + \Delta h_b$ $\Delta h_m = [4.77/(1+0.43U/V)]\cdot\sqrt{Q_v\cdot V}/U$ $\Delta h_b = 6.37g\frac{Q_v\cdot\Delta T}{U^3\cdot T_a}(\ln J^2 + \frac{2}{J} - 2)$ $J = \frac{U^2}{\sqrt{Q_v\cdot V}}(0.43\sqrt{\frac{T_a}{g\Delta\theta/\Delta z}} - 0.28\frac{V}{g}\frac{T_a}{\Delta T}) + 1$	Theoretical (Bosanquet)	Unstable to neutral $\Delta\theta/\Delta z = 0.003$	70~1500	—	3.1~8.1	8~10.8
2 Bosanquet 2nd formula	1957	$\Delta h = AU[f_I(a)+f_{II}(a_0) - \{0.615a_0^{1/2}/(<V/U>^2+0.57)^{1/2}\}]$ $A = g\cdot Q_v\cdot\Delta T/2\pi C^2 Ta^{\circ}U^4$ $a = (t+t_0)/A = (t/A_2)+a_0$ $a_0 = t_0/A \quad t = x/U \quad t_0 = 4\cdot V\cdot Ta/3g\Delta T$ $t+t_0 = 20$ sec, $C = 0.13$ $f_I(a)$, $f_{II}(a_0)$	Theoretical (Bosanquet)	Unstable to neutral $t + t_0 = 200$ sec at stable $t + t_0 = 1.572$ $\times [2T_0/g\Delta\theta/\Delta z]^{1/2}$	70~1500	—	3.1~8.1	8~10.8
3 Bosanquet II modified at CRIEPI	1965	Diffusion coefficient $C=0.13$ of Bosanquet 2nd formula replaced by $C=0.26U^{-1/2}$	Theoretical (Bosanquet)	Same as above	1500~17000	80~200	1~15	13.2~35
4 CERL formula (Lucas 2nd *formula*)	1967	$\Delta h = (104+0.17\,H_s)Q_H^{1/4}/U$	Theoretical (Priestley)	Consideration not given	7000~25000	76~183	1.5~11.3	14~24.5
5 Moses & Carson formula	1968	$\Delta h = (C_1\,VD + C_2\,Q_H^{1/2})/U$ $C_1 = 0.35$, $C_2 = 5.41$ (at neutral)	Regression equation	C_1, C_2 different at unstable or stable	2~2500	34~183	1~11.7	2.2~24.5
6 CONCAWE formula	1968	$\Delta h = 5.53\,Q\pi^{1/2}U^{-3/4}$	Regression equation	Consideration not given	70~4000	—	4~10	3.3~17
7 Briggs formula	1969	$\Delta h = 1.6F^{1/3}U^{-1}(3.5x^K)^{2/3} \quad x^K = 34F^{2/5}$ ($F>55$ m⁴/sec²) $\Delta h = 5.35\,Q_H^{0.6}/U$ ($Q_H > 1500$ kcal/sec)	Dimensional analysis (Briggs)	Applied at unstable to neutral, another formula for stable	1000~21000	61~183	1.8~16.5	5.5~28.9
8 TVA formula	1971	$\Delta h = 114CF^{1/3}/U$, $C=1.58-41.4\Delta\theta/\Delta z$ $\Delta\theta/\Delta z = 0 \quad \Delta h = 60Q\pi^{1/3}/U$	Dimensional analysis	$\Delta\theta/\Delta z>0.003$	7000~25000	76~183	1.5~11.3	14~24.5
9 Okamoto, Okanishi and Shiozawa formula	1979	$\Delta h = 5.5Q\pi^{1/2}/U^{3/5}$	Regression equation	Consideration not given	100~47000	20~366	1~17	2~40

1.2 Development of SO_2, NO_x and NO_2 Diffusion Prediction Model

There are various air pollution prediction methods as described in the preceding section. Each of these methods has its own advantages and disadvantages. The method to be used for prediction of air pollution must be determined depending on the purpose of prediction, complexity of computation, the geography of the area and other conditions. The purpose of this study is to calculate the degree of contribution of pollutant sources at present and in the future at Samut Prakarn province in Thailand. In a prediction, it is necessary to calculate the long-term average concentration (annual average) while considering the occurrence frequency of the various meteorological conditions. The region is relatively flat in geography so that the effect of the topography on the diffusion space may safely be ignored.

For these reasons, in this study, the Gaussian plume model and the Gaussian puff model were employed as the diffusion models to calculate the diffusions of all emission sources in Samut Prakarn province in 1988 and to check the agreement between the calculated and actual values measured at stations. Then, parameters such as pollutant emission volume, diffusion parameters, etc. used in this calculation was verified to develop the diffusion prediction models for the SO_2, NO_x and NO_2 pollutants. These SO_2, NO_x and NO_2 diffusion prediction models consist of the meteorological model, the source model, the diffusion model, the NO_2 conversion model and the annual average prediction model as shown in Fig. 1-8. The components of each model are listed in Table 1-4.

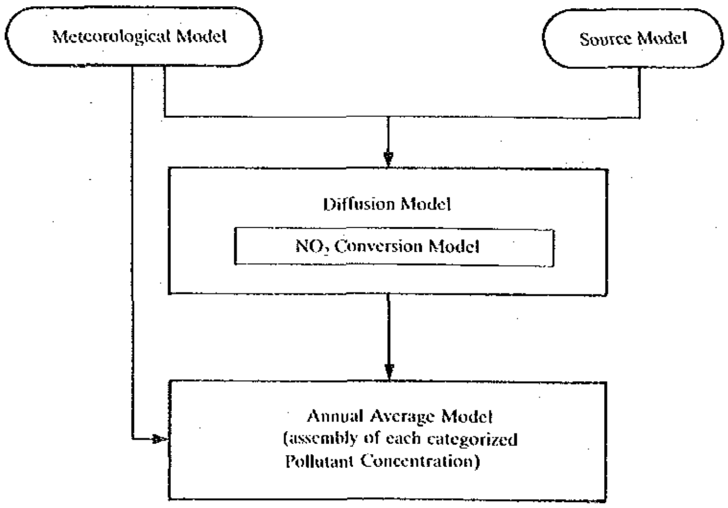


Fig. 1-8 Schematics of SO_2, NO_x and NO_2 Prediction Models

Table 1-4 Components of SO_2, NO_x and NO_2 Prediction Models

Component	Content	Description
Meteorological Model	Meteorological frequency	Frequency of occurrence by wind direction, wind velocity and atmospheric stability
	Upper layer wind velocity equation	Calculation by law of exponent
	Ground level wind velocity equation	Calculation by law of exponent
Source Model	Source data	Information such as position, height, emission volume, etc. of each source
	Plume rise equation	Calculation by CONCAWE equation or Briggs equation
Diffusion Model	*Diffusion equation*	*Calculation by Gaussian plume equation or Gaussian puff* equation
	Diffusion width	Windy: Yamamoto and Yokoyama's method was employed for factories and ships. The highway model diagram was used for cars. *Calm: Diffusion width under the calm condition by specified by* the Ministry of International Trade and Industry was adopted.
NO_2 Conversion Model	NO_2 conversion equation	Exponent approximation type NO to NO_2 conversion equation
	Conversion speed	NO to NO_2 conversion rate coefficient
	O_3 background	Center value by atmospheric stability of ozone concentration measured over ONEB roof was used.
Annual average prediction model	Annual average calculation	Concentration by meteorological condition was weight-averaged accounting for its meteorological frequency and the annual average was calculated.

1.2.1 Meteorological Model

The meteorological conditions governing the atmospheric transport and diffusion were treated as represented by wind direction velocity and atmospheric stability and, thus modelling of the *meteorological conditions was made for use in the diffusion calculation as discussed below.*

(1) Grouping of Meteorological Conditions by Season and Time Zone

The seasonal variation and daily variation of meteorological conditions as described in Part III of Section 1.1.1 were divided by seasons and time zones as shown in Table 1-5. Then the agreement between the measured values and the calculated ones was checked with respect to such divisions.

Table 1-5 Grouping of Meteorological Conditions by Season and Time Zone

Season Time	Wet Season May to October	Dry Season November to January	Intermediate February to April
Daytime	7:00 to 17:59	7:00 to 17:59	7:00 to 17:59
Nighttime	18:00 to 6:59	18:00 to 6:59	18:00 to 6:59

(2) Division into Meteorological Blocks

The area of Samut Prakarn is nearly uniform in meteorological conditions as stated in Part III of 1.1.5 so that the diffusion may be calculated using the meteorological conditions measured at any of the MS1, MS2 and MS5 stations. When calculating the atmospheric concentration at a mesh point, however, the best reproduction of actual concentration is expected by the use of meteorological conditions measured at the station closest to the mesh point. Therefore, the area was divided into the three meteorological blocks as shown in Fig. 1-9 taking such factors into account as the meteorological correlation among measuring stations, the geography of the area, and the distribution of the pollutant sources, etc. The diffusion calculation was conducted for the two cases, namely, one with MS3 and MS4 (on which meteorological conditions were not monitored) included in the same block of MS1 and the other with MS3 and MS4 included in the block of MS2. It was found that the latter case gave a better agreement between the measured and calculated values. Thus, the division into the meteorological blocks was finally adopted as shown in Fig. 1-9. In the diffusion calculation of ambient pollutants released from factories and ships, the meteorological conditions (occurrence frequency of wind direction, wind velocity and atmospheric stability) of the area where such sources located were applied and in the calculation of the pollutants released from vehicles, the meteorological conditions of the block to which the mesh point belonged were used.

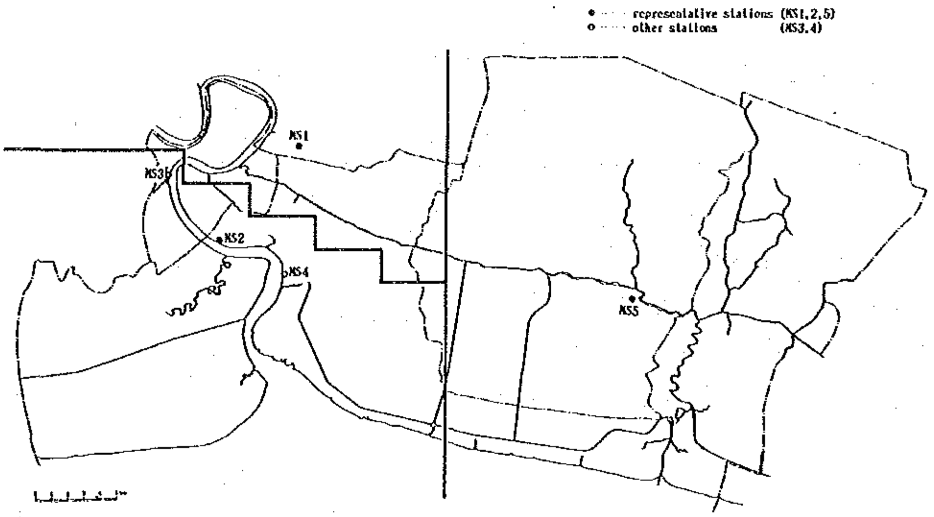


Fig. 1-9 Division into Meteorological Blocks and Representative Stations

(3) Wind Direction and Velocity

The wind direction was divided into 16 directions as shown in Fig. 1-10 and the wind velocity into six ranks as shown in Table 1-6, with representative wind velocity established for each rank.

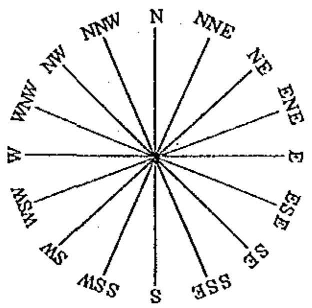


Fig. 1-10 Wind Direction Division

Table 1-6 Wind Velocity Ranking and Representative Wind Velocity

Wind velocity rank		Representative wind velocity
Calm	0~0.4 m/s	CALM
Windy	0.5~0.9 m/s	0.7 m/s
	1.0~1.9 m/s	1.5 m/s
	2.0~2.9 m/s	2.5 m/s
	3.0~4.9 m/s	4.0 m/s
	5.0~ m/s	6.0 m/s

(4) Atmospheric Stability

In this study, applied was the stability classification of the Ministry of International Trade and Industry of Japan which is based on Pasquill's stability classification but uses net radiation flux instead of cloud amount (Table III-1-6). According to this classification, the stability was classified into ranks A to F in windy condition and ranks CA to CD in calm condition. The diffusion width for use in the diffusion calculation was set according to these atmospheric stability ranks (to be discussed later).

(5) Estimation of Upper Layer and Surface Wind Velocity

In the planetary boundary layer up to an altitude of about 2 km, the wind velocity decreases with decreasing altitude. This is because of the influences of surface roughness and hydrodynamic head loss of atmospheric fluid. This means that smoke released at a lower altitude near the ground surface and smoke released at a higher altitude behave and diffuses differently. In this study, therefore, the air layer was divided into upper, middle and surface layers according to the level of emission sources and the wind velocity in the upper and in surface layers was estimated as listed in Table 1-7.

Table 1-7 Wind Velocity Used in Diffusion Calculation[10]

Layer	Pollution sources	Wind velocity application
Upper	Stationary source with actual stack height 30 m or higher	Wind velocity at actual stack height was estimated by law of exponent.
Middle	Stationary source with actual stack height lower than 30 m and ship	Wind velocity at the representative station was applied as it was.
Surface	Cars	Wind velocity at 3 m above ground was estimated by law of exponent.

In the estimation of wind velocity in the upper layer and ground surface, Equation (1-10) was used. In the equation, the value of index P should ideally be determined by analysis of the data continuously measured in the upper air layer of Samut Prakarn. In this study, however, such data was not available and so the value of P used in the CDA Manual by the EPA of the U.S. (Table 1-8) was adopted.[11]

$$U_z = U_{z0}\left(\frac{Z}{Z_0}\right)^P \quad \text{.......................} \quad (1\text{-}10)$$

where;

U_z: Wind velocity at altitude Z (m/s)

U_{z0}: Wind velocity at altitude Z_0, MS1; Z_0:30 m, MS2 and 5; Z_0: 10 m

p: Constant that depends on the meteorological conditions (exponent)

Table 1-8 Value of Exponent P

Stability	A	B	C	D	E	F • G
P	0. 1	0. 15	0. 2	0. 25	0. 25	0. 3

Note: These values were reported by De Marrais[11] based on the wind velocity measured on the ground and at the top of a 145 meter high tower located in Brookhaven. The data represents the geography of a gently sloped area near the sea scattered with pine-trees.

1.2.2 Source Model

In order to use the source data collected and consolidated by factories, cars and ships in the diffusion calculation, the sources were modeled as shown below.

(1) Smoke Source Type

The sources were classified into the smoke types shown in Table 1-9.

Table 1-9 Classification of Sources for the Diffusion Calculation

Source		Smoke type
Stationary	*Factories covered by the questionnaire*	*Point sources*
	Factories not covered by the questionnaire	Area sources of 2 km by 2 km
Cars		Line sources
Ships	Vessels (sailing)	Point sources
	Ferries (at anchor)	Point sources
	Ferries (sailing)	Point sources

(2) Time Changing Source Activity

For stationary sources, the volume of pollutants released was calculated by season and by time zone (Table 1-5) with respect to the facility operating status and operating time zone (see Part IV of Table 2-9). As for cars and ships, the variations in traffic volume and number of ships by daytime and nighttime determined by the field survey were taken into consideration. The seasonal variation was ignored because of insignificant monthly variations in the traffic volume and in number of ships.

(3) Effective Stack Height

1) Effective stack height of stationary (point) source

The effective stack height is the actual stack height (H_0) plus the plume rise (ΔH) of smoke. The following plume rise equations were used.

① Windy condition: CONCAWE equation

$$\Delta H = 0.175 \cdot Q_H^{\frac{1}{2}} \cdot U^{-\frac{3}{4}} \quad \text{......} \quad (1\text{-}11)$$

where;

$Q_H = \varrho \cdot Q \cdot C_P \cdot \Delta T$ (cal/s) (released heat)

$\varrho = 1.293 \times 10^3$ g/m^3 (air density at 0°C)

C_P=0.24 cal/g·°K (isopiestic specific heat)

Q: Volume of gas emitted (Nm^3/s)

ΔT: Temperature difference between exhaust gas and atmosphere

$\Delta T=(T_G-28)$°C

T_G: Exhaust gas temperature (°C)

U: Wind velocity at stack top (m/s)

② Calm condition: Briggs stable state equation

$$\Delta H = 1.4 \cdot Q_H^{\frac{1}{4}} \cdot (d\theta/dz)^{-\frac{3}{8}} \quad \text{......} \quad (1\text{-}12)$$

where the following values were used for $d\theta/dz$.

Daytime: $d\theta/dz$=0.005°C/m (average temperature gradient)

Nighttime: $d\theta/dz$=0.010°C/m (isothermal layer)

2) Effective stack height of stationary source (area source)

Considering an actual stack height of about 20 m, the effective stack height was set at 30 m.

3) Car effective stack height

The effective stack height of cars was set at 3 m$^{10)}$.

4) Ship and ferry effective stack height

The effective stack height of ships was set at 20 m. That of ferries was set at 5 m.$^{10)}$

1.2.3 Diffusion Model

In this study, the Gaussian plume model and the Gaussian puff model were used. The diffusion calculation equations and diffusion width used are described below.

(1) Diffusion Equation

The diffusion equations listed in Table 1-10 were applied according to the smoke source types. The diffusion equation is as shown below.

Table 1-10 Sources and Diffusion Equations Used

Source	Smoke source type	Diffusion equation	
		Windy (u>0.4 m/s)	Calm (u≦0.4 m/s)
Stationary point source and ship	Point sources	Plume equation {Equation (1-13)}	Puff equation {Equation (1-14)}
Stationary area source	Area sources	Area smoke source plume equation {Equation (1-15)}	Area smoke source puff equation {Equation (1-16)}
Car	Line sources	Line smoke source plume equation {Equation (1-18)}	Line smoke source puff equation {Equation (1-19)}

1) Plume Equation (applied to point sources under the windy condition)

The diffusion concentration by the plume equation can be expressed by the equation (1-13). The ground surface just under the smoke source is set as the origin, and the x-axis is set in the leeward direction from the origin and the y-axis in the horizontal direction at a right to the x-axis. The z-axis is set in the vertical direction.

$$C(x, y, z) = \frac{Q_P}{2\pi\sigma_y\sigma_z u}\cdot\exp\left(-\frac{y^2}{2\sigma_y{}^2}\right)\left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z{}^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma_z{}^2}\right\}\right] \quad \ldots \text{(1-13)}$$

where;

x: x coordinate of the calculation point (m)
y: y coordinate of the calculation point (m)
z: z coordinate of the calculation point (m)
Q_P: Intensity of the point smoke source (m^3/s)
u: Wind velocity (m/s)
He: Effective stack height (m)
C(x, y, z): Concentration at the calculation point (x, y, z)
σ_y: Diffusion width of smoke in y direction (m)
σ_z: Diffusion width of smoke in z direction (m)

2) Puff Equation (applied to point smoke source under the calm condition)

The concentration of atmospheric diffusion by a point sources under the calm condition was calculated by the equation (1-14).

$$C(R, z) = \frac{Q_P}{(2\pi)^{3/2}\gamma}\left\{\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(He-z)^2}+\frac{1}{R^2+\frac{\alpha^2}{\gamma^2}(He+z)^2}\right\} \quad \ldots\ldots\ldots\ldots\ldots \text{(1-14)}$$

where, R is the horizontal separation (m) between the point smoke source and the calculation point and thus $R^2=x^2+y^2$ and are the proportional constants of the diffusion width and the transportation time T(s) and thus $\alpha=\sigma_y/T$ and $\gamma=\sigma_z/T$. As the duration of calm condition is at most one hour or so as observed during field surveys, the values of α and γ at T=3600 sec. were used.

3) Plume Equation for Area Smoke Sources (applied to area sources under the windy condition)

Because the stationary area sources cannot be easily located, it was handled as a 2 km by 2 km area source. The diffusion concentration by the area smoke sources were calculated by subdividing the area source into small $d\eta \times d\xi$ sources as shown in Fig. 1-11. These small sources were considered as point smoke sources and the concentration was calculated by surface-integration of the equation (1-13).

$$C(x, y, z) = \int_{x-a}^{x+a}\int_{y-a}^{y+a} \frac{Q_A}{2\pi\sigma_y\sigma_z u}\cdot\exp\left(-\frac{\eta^2}{2\sigma_y^2}\right)$$

$$\times\left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right]d\eta d\xi \quad \text{.........} \quad (1\text{-}15)$$

where;

Q_A: Release rate per unit area ($m^3/s/m^2$)

a: 1/2 of area source side length (m)

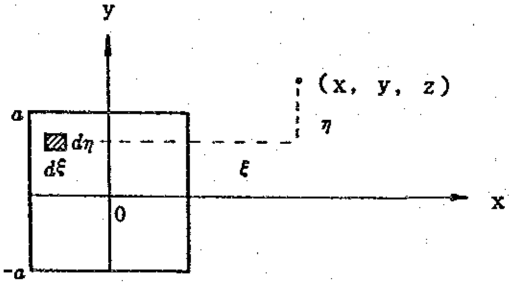


Fig. 1-11 Conceptual View of Surface Smoke Source (windy case)

If the calculation point is within the area source (x<a), the x integration range is x−a to x.

4) Puff Equation for Area Sources (applied to an area source under the calm condition)
For convenience of calculation, the diffusion concentration by the area sources was calculated by setting the 2 km by 2 km square area source being equivalent to a circle of the same area, namely a radius a′=1.13 km as shown in Fig. 1-12, subdividing it into small dθ×dr smoke sources, then regarding these small sources as the point smoke sources and integrating the point source puff equation (1-14) as shown below.

$$C(R, z) = \int_0^{a'}\int_0^{2\pi}\frac{Q_A}{(2\pi)^{3/2}\gamma}\left\{\frac{1}{R'^2+\frac{\alpha^2}{\gamma^2}(He-z)^2}+\frac{1}{R'^2+\frac{\alpha^2}{\gamma^2}(He+z)^2}\right\}rdrd\theta \quad (1\text{-}16)$$

where;

a′: Radius of equivalent circular smoke source (m)

R′: $R' = \sqrt{R^2+r^2-2rR\cos\theta}$

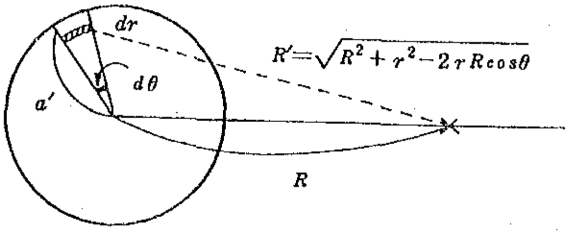


Fig. 1-12 Conceptual View of Area Sources under the Calm Condition

5) Plume Equation for Line Sources (applied to line smoke source under the windy condition)
The ground level concentration by exhaust gas from a line source can be determined by line-integrating the point source equation, Equation (1-13). Practically, it was calculated by subdividing the line source into N equal parts as shown in Fig. 1-13, and regarding them as the point sources and superposing the point source equations.

$$C(x,\ y)=\sum_{i=1}^{N}\frac{Qi}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{{y_i}^2}{2{\sigma_y}^2}\right)\left\{\exp\left(-\frac{(He-z)^2}{2{\sigma_z}^2}\right)+\exp\left(-\frac{(He+z)^2}{2{\sigma_z}^2}\right)\right\}\ \ldots\ (1\text{-}17)$$

where,

Q_i: Emission rate of No.i subdivision line source (point source) (m^3/s)
y_i: Distance between the calculation point and the x-axis parallel to the wind direction and passing through the center of the No.i subdivision line source (m)

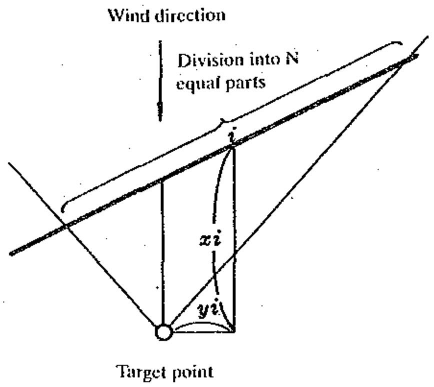


Fig. 1-13 Conceptual View of Atmospheric Diffusion Concentration Calculation by Line Source Diffusion Equation (under the Windy Condition)

6) Puff Equation for Line Sources (applied to line sources under the calm condition)
The atmospheric diffusion concentration under the calm condition from a car line source can be determined by line-integrating the point source puff equation, Equation (1-14). Actually, it was calculated, as such was the case with the calculation of the point source under the calm condition, by letting $\sigma_y=\alpha T$ and $\sigma_z=\gamma T$, subdividing the angle θ between the calculation point to the road line into equal angles (Fig. 1-14), substituting the point

sources for the line sources, calculating the diffusion concentrations and superposing these concentrations.

$$C(R) = \sum_{i=1}^{N}\left[\frac{Qi}{(2\pi)^{3/2}\alpha^2\gamma}\left\{\frac{1}{\frac{r_i^2}{\alpha^2}+\frac{(He-z)^2}{\gamma^2}}+\frac{1}{\frac{r_i^2}{\alpha^2}+\frac{(He+z)^2}{\gamma^2}}\right\}\right] \quad \cdots\cdots\cdots\cdots\cdots (1\text{-}18)$$

where;

Q_i: Emission rate from small segment obtained by subdivision of the line source into N equal parts (m^3/s)

r_i: Distance between the calculation point and small segment obtained by subdivision of the line source into N equal parts (m)

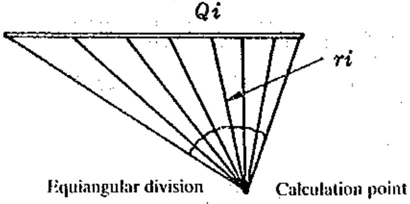


Fig. 1-14 Conceptual View of Atmospheric Diffusion Concentration by Line Source Diffusion Equation (under the calm conditions)

(2) Diffusion Parameter (Diffusion Width)

For numerical calculation of the ambient air using the diffusion equation, it is necessary to give specific values to the diffusion width in the equation. In this study, the following diffusion widths were used depending on the smoke source height:

Stationary source, ship and ferry under the windy condition ... Yamamoto & Yokoyama's equation
Car under the windy conditions..HIWAY diagram
Calm condition...MITI diagram

1) Diffusion Widths of Stationary Source, Ship and Ferry when with Wind

The atmospheric diffusion concentrations of the pollutants emitted from the stationary source, ship and ferry under the windy condition were calculated using Yamamoto & Yokoyama's diffusion parameter$^{12)}$.

$$\left.\begin{aligned}\sigma_y &= 0.018\ \sigma_A\cdot x\\ \sigma_z &= 0.0054\ k\sigma_E\cdot x\end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots (1\text{-}19)$$

where; σ_y and σ_z are the diffusion widths (m) in the horizontal and vertical directions. σ_A and σ_E are the standard deviations (deg.) in the horizontal and vertical directions. x and k are the constants determined by the leeward distance (m) and the atmospheric stability, respectively. The constant k values are listed in Table 1-11. This table also contains σ_A and σ_E values by the stability calculated from the atmospheric turbulence values measured with an ultrasonic wind direction and velocity meter. Fig. 1-15 shows the relationship between the leeward distance x and the σ_y and σ_z values by the atmospheric stability calculated from the Equation (1-19) using these values. In comparison with the P-G diagram, the horizontal diffusion width σ_y obtained by Yamamoto/Yokoyama's diffusion width is much larger than that based on the P-G diagram. This is because the P-G diagram represents a three-minute diffusion width while Yamamoto/Yokoyama's represents a one-hour diffusion width.

Table 1-11 Diffusion Parameter K, σ_A and σ_E by Atmospheric Stability Classifications

Parameter	A, B	C	*D daytime*	*D Nighttime*	E	F
K Values	2.67	2.04	1.0	1.0	0.83	0.83
σ_A (degree)	26.1	21.6	21.1	20.3	20.0	18.9
σ_E (degree)	11.7	8.8	7.9	7.5	6.7	6.2

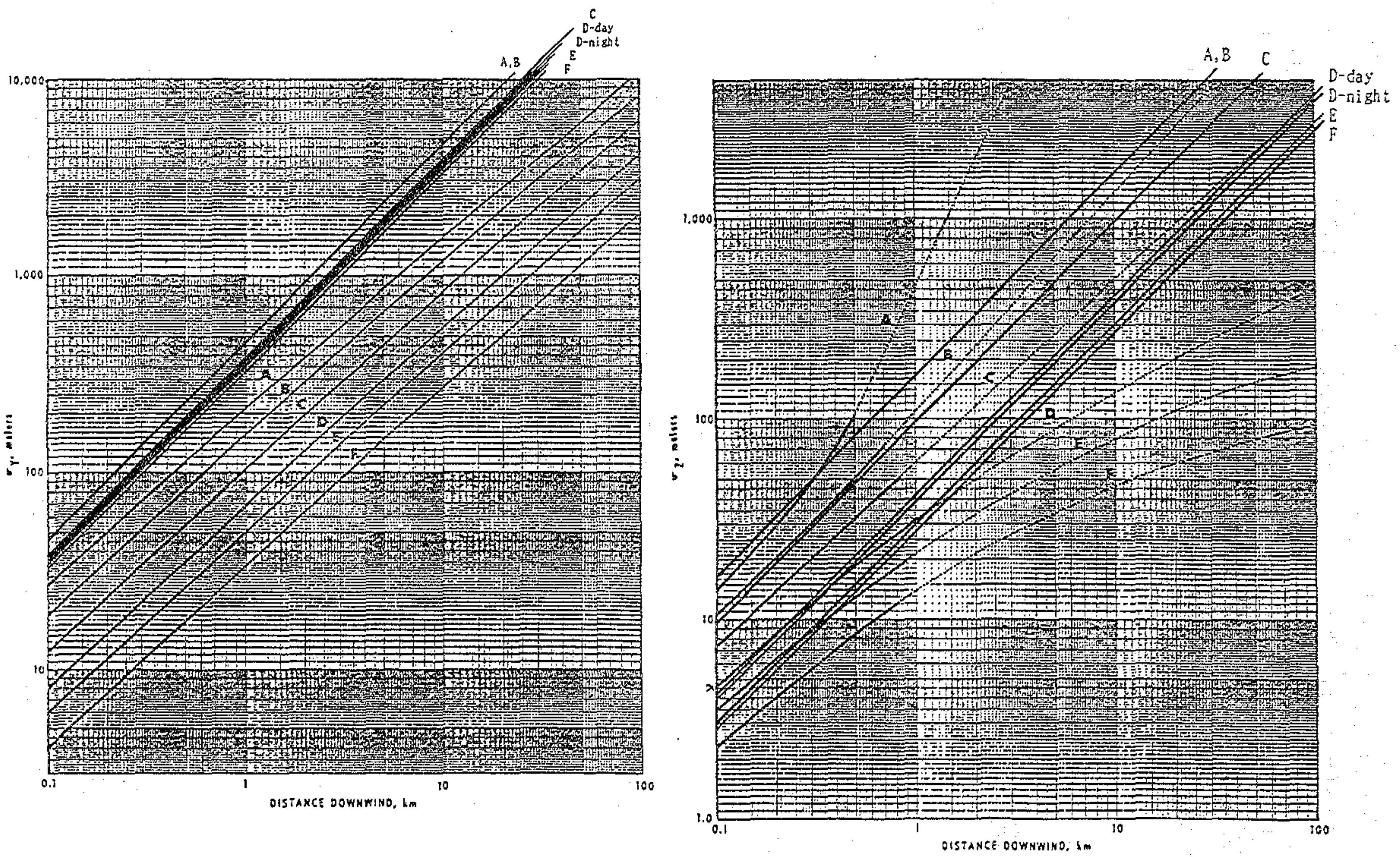


Fig. 1-15 Yamamoto/Yokoyama's Diffusion Width

2) Diffusion Widths of Cars under the Windy Condition

The diffusion widths of cars under the windy condition were calculated using the HIWAY diagram of the EPA[13]. These diffusion widths are expressed by the Equation (1-20) and shown in Fig. 1-16.

$$\left.\begin{aligned} \sigma_y &= 465.1(x+b)\tan\theta_P \\ \theta_P &= c-d\cdot\ln\left(\frac{x+b}{X_0}\right) \\ \sigma_z &= g\left(\frac{x+a}{X_0}\right)^h \end{aligned}\right\} \qquad \cdots\cdots \quad (1\text{-}20)$$

where;

x: Leeward distance (km)
a: Coefficient for initial diffusion width σ_{z0} (km)
b: Coefficient for initial diffusion width σ_{y0} (km)
c: Coefficient for θ_p (deg.)
d: Coefficient for θ_p (deg.)
g: Coefficient for σ_z (m)
h: Exponent for σ_z
θ_p: A half of the angle at which plume varies on the horizontal face
X_0: =1 km

These coefficient values are listed in Table 1-12. They have been set for σ_z of about 1.5 m at x=0 m, σ_y of about 3 m (a half of a car length) and for agreement with the Pasquill-Gifford diagram.

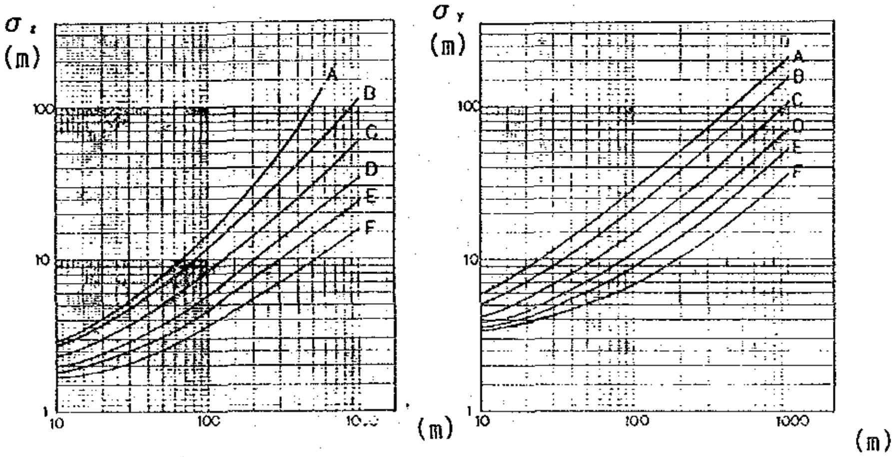


Fig. 1-16 Diffusion Widths in HIWAY Model

In order to improve the consisting between the measured values and calculated values in the actual calculations, the diffusion width was deviated a half rank to the unstable side (e.g., the diffusion range B−C was used in case of Atmospheric stability C rank).

Table 1-12 Coefficients of σ_y, σ_z used in HIWAY Model

Step of HIWAY model diagram	Distance (km)[Note 1]		Value for θ_p (deg.)		Other	
	a	*b*	*c*	*d*	*g* (m)	*h*
A	0.00944	0.00863	24.167	2.5334	122.8	0.9447
B	0.01226	0.0132	18.333	1.8096	90.673	0.93198
C	0.01736	0.0210	12.5	1.0857	61.141	0.91465
D	0.02722	0.0348	8.333	0.72382	34.459	0.86974
E	0.03590	0.0471	6.25	0.54287	24.26	0.8366
F	0.05842	0.0733	4.167	0.36191	15.209	0.81558

Note 1: a and b are the coefficients for the initial diffusion widths σ_{y0} of 3.0 m, σ_{z0} of 1.5 m.

3) Diffusion Widths under the Calm Condition

The estimation method of the diffusion widths under the calm condition has not yet been established well. In general, the Turner diagram may be applicable. However, even when there is no wind at about 10 m above the ground, there is wind in the upper layer. Therefore, if the concentrations under the calm condition are calculated using this Turner diagram, they may not agree well with the measured values. The Ministry of International Trade and Industry reported that if the atmospheric diffusion concentrations under the calm condition are calculated by using the diffusion widths several times larger than the values listed in the Turner diagram, they reproduce well the measured values. This diagram is shown in Fig. 1-17. In this study, the atmospheric diffusion concentrations under the calm condition were calculated using this diagram.

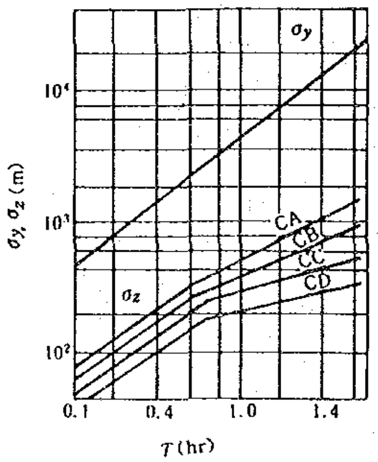


Fig. 1-17 Atmospheric Diffusion Widths under the Calm Condition by the Ministry of International Trade and Industry[10]

4) Initial Diffusion Width (σ_{z0})

① Stationary Source (Point Source)

The plume rise ΔH changes with the wind velocity so that ΔH will change and smoke will disperse vertically near the sources if the wind velocity changes. Therefore, if the plume rise is higher, its variation becomes larger and the initial dispersion width σ_{z0} becomes larger as well. By comparing the TVA diagram[14)] developed based on the actual stack data and the diagram obtained from the point source diffusion tests, and also with assumption that the value of σ_z at the short distance value (x=100 m) being equal to the initial diffusion width σ_{z0} caused by plume rise. The initial diffusion width becomes about 25 m under highly stable condition or about 30 m under unstable condition.

Here, the initial diffusion width σ_{z0} of the stationary source (point source) was assumed to increase with the plume rise ΔH, 30 m under unstable and neutral conditions at $\Delta H = 100$ m and 25 m when it was stable. The value σ_{z0} does increase with increasing ΔH but by taking the data on which the TVA diagram originates and other factors into consideration, it was assumed that the initial diffusion width would reach its upper limit value at $\Delta H = 100$ m and it would not increase further even if ΔH becomes higher. The lower limit value was set at 5 m. The assumed relationship is illustrated in Fig. 1-18.

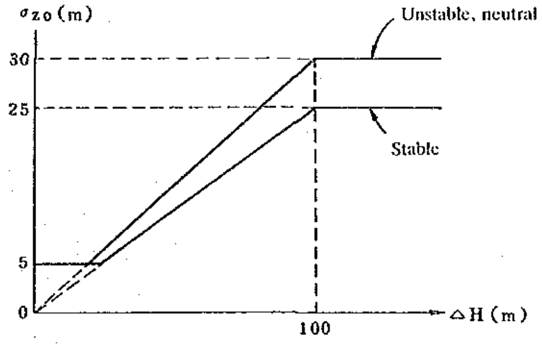


Fig. 1-18 Initial Diffusion Width σ_{z0} of Stationary Source (Point Source)[10)]

② Stationary Source (Area Sources), Car, Ship and Ferry

The initial diffusion width σ_{z0} of the stationary source (area source), car, ship and ferry was set at 5 m[10)].

1.2.4 NO_2 Conversion Model

When atmospheric hydrocarbons and NO_x is exposed to the sunlight for a prolonged period, it undergoes complex photo chemical reactions, including oxidation of NO, decomposition of NO_2 and creation of oxidants. When the diffusion time is limited to a short period of one to two hours, however, nitrogen oxides (mostly NO) that are emitted from a stack or car will react with ozone as they diffuse to form NO_2. The main reactions involved here are oxidation of NO by ozone and dissociation into NO by ultraviolet rays. Fig. 1-19 shows the NO_x and O_3 distributions in a smoke stream measured by a group of Washington University.[15] It is seen that O_3 concentration was low where NO_x concentration was high, indicating the reaction of NO with O_3.

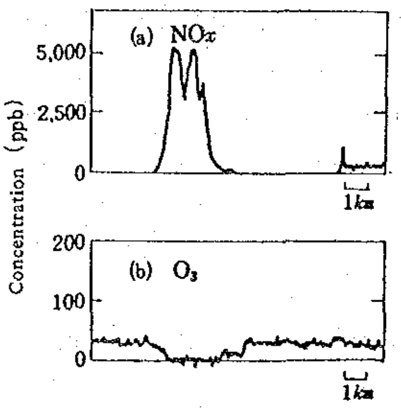


Fig. 1-19 NO_x and O_3 Concentration in Plume Concentration (ppb)

For use in combination with the plume or puff diffusion model to calculate NO and NO_2 concentrations, Yamamoto and Yokoyama[16] developed the following simple empirical formula from field test results.

$$C_{NO_2} = C_{NO_X}\{1-\alpha e^{-kt}\} \quad \cdots\cdots \quad (1\text{-}21)$$

Here, C_{NO_x} is the NO_x concentration obtained from the diffusion calculation equation and the concentration is assumed to be maintained. α and k are test constants. In Equation (1-21), C_{NO_2}/NO_x becomes 100% when $t \rightarrow \infty$. In the nighttime, however, an equilibrium is attained with $\frac{[NO]\cdot[O_3]}{[NO_2]}$=Const.) due to oxidation by ozone, dissociation into NO by ultraviolet rays, etc. and 100% conversion of NO into NO_2 does not take place. In the nighttime, 100% conversion is considered possible if ozone is present because of an absence of dissociation into NO. In the actual atmosphere, however, the NO_2/NO_x ratio in the nighttime remains nearly the same at 80% or so as during the daytime. This may be explained as follows: during nighttime, no ozone is produced but it is supplied from the higher atmosphere. When ozone so supplied is consumed in the reaction with NO_x, no further reaction takes place. The fact that both ozone and NO are found in the measurement of the atmosphere would be because bulk of pollutants exists heterogeneously both in terms of space and time and the average calculated reflects them. Therefore, in this study, Equation (1-22) was used to calculate NO_2 concentration instead of Equation (1-21).

$$C_{NO_2} = C_{NO_x}\left\{1-\frac{\alpha}{1+\beta}(e^{-kt}+\beta)\right\} \quad \cdots\cdots \quad (1\text{-}22)$$

where;

C_{NO_x}: NO_x concentration calculated by the diffusion calculation equation

α: NO/NO_x ratio in initial stage of diffusion ($\alpha=0.9$)

β: Constant to suppress NO to NO_2 conversion ($\beta=0.3$)

k: Apparent reaction speed constant

$k=0.0062 \cdot u \cdot Co_3$ (Stationary source)

$k=0.062 \cdot u \cdot Co_3$ (Stationary area source, ship)

$k=0.208 \cdot u \cdot Co_3$ (Car)

Co_3: Ozone background concentration

u: Wind velocity (m/s)

As for the ozone background concentration, the values (one-hour values) measured at the roof of ONEB for a period of one year in 1988 were grouped by the atmospheric stability, and their medians were used. When calculating NO_2 atmospheric diffusion concentration from the road, the ozone background concentration was corrected by Equation (1-23)[10]. This is to take account of the decrease of ozone supplied to the background when the wind direction is parallel to the road (when the angle between the road and wind direction is 30 degrees or smaller).

Table 1-13 Ozone Background Concentration

Ozone concentration (ppm)	Daytime		Nighttime	
	Unstable	Neutral	Neutral	Unstable
	0.014	0.010	0.005	0.005

$$\left.\begin{array}{ll}\text{Daytime} & [O_3]_{BG}\ \text{parallel wind}=0.55\times[O_3]_{BG} \\ \text{Nighttime} & [O_3]_{BG}\ \text{parallel wind}=0.33\times[O_3]_{BG}\end{array}\right\} \quad \cdots\cdots (1\text{-}23)$$

1.2.5 Annual Average Value Model

The diffusion calculation was conducted for each categorized meteorological condition (combination of wind direction, wind velocity and atmospheric stability) and, from the calculated results and the frequency of occurrence of respective meteorological conditions, the annual average concentration was calculated as shown below.

① Calculation of Average Concentration under the Windy Condition

$$\overline{C} = \sum_i \sum_j \sum_k C(D_i, V_j, S_{tk}) \cdot f(D_i, V_j, S_{tk}) \quad \cdots\cdots (1\text{-}24)$$

where;

$C(D_i, V_j, S_{tk})$: One-hour concentration with wind direction D_i, wind velocity V_j, stability class S_{tk}

$f(D_i, V_j, S_{tk})$: Frequency of occurrence with wind direction D_i, wind velocity V_j, stability class S_{tk}

② Calculation of Average Concentration under the Calm Condition

$$\overline{C} = \sum_k C(S_{tk}) \cdot f(S_{tk}) \quad \cdots\cdots (1\text{-}25)$$

where;

$C(S_{tk})$: Concentration with stability class S_{tk}

$f(S_{tk})$: Frequency of occurrence with stability class S_{tk}

These calculations under the windy and calm conditions were made for each season and time period and the average was determined taking the frequency of occurrence into consideration.

1.2.6 Comparative Study on Calculated and Measured Values

Calculation of ambient pollutant concentrations were done by using all SO_2 and NO_x data from sources (factories, cars, vessels and ferries) opereating in Samut Prakarn province in 1988 and agreement between the measured values and the calculated values at the monitoring station was checked. This calculation was done five times in total until a good agreement was obtained as shown in Table 1-14.

(1) Evaluation of Agreement on Calculated and Measured Values

The yearround values of measured and calculated concentrations by season and by time zone are listed in Table 1-15. The distribution of the measured and calculated values is shown in Fig. 1-20. The result of evaluation of these calculated values in terms of the criteria$^{17)}$ of the applied simulation model shown below is given in Table 1-16. From these results, it was found that the agreement of the yearly concentrations drops in the rank A except that of SO_2 (during the night-time zone) which is the rank C, and thus the simulation model used in this study is considered having a feasible accuracy.

① The difference (a_0) between the average $(\overline{Y})$ of measured values and the average $(\overline{X})$ of calculated values should satisfy the following condition.

$$a_0 \leqq \left\{ \frac{1}{3}(\overline{Y} - BG) + BG \right\}$$

BG: Background concentration

② The a_0 shall be within the following range.

$$a_0 \leqq \left\{ \frac{2}{5}(\overline{Y} - BG) + BG \right\}$$

③ The correlation coefficient must be more than 0.71 and exceed 0.80 (preferably bigger). The regression coefficient (a) must be from 0.8 to 1.2.

④ The estimated error rate $(S'/\overline{Y})$ must not exceed 1/5.

⑤ S'/$\overline{Y}$ must not exceed 1/4.

⑥ S'/$\overline{Y}$ must not exceed 1/3.

The ranks are established by combining criteria ① to ⑥ as shown in the following table.

Evaluation Rank	Criteria
A	①, ③ and ⑤, or ① and ④ satisfied.
B	② and ⑤ satisfied.
C	② and ⑥ satisfied.

The following evaluation ranks are desirable, with respect to season and time period.

		Seasonal Category	
		Each Season	Whole Year
Time Zone Category	Each Time zone	C	B
	All day	B	A

Table 1-14 Process of SO_2, NO_x and NO_2 Environmental Concentration Simulation Improvement

	Condition	First	Second	Third	Fourth	Fifth
Car	Diffusion width	P-G diagram	HIWAY diagram			The diffusion width was deviated a half rank to the unstable size from the HIWAY diagram
	Weight of diesel car	Heavy ... 5.5 t Light ... 1.62 t	Heavy ... 9.75 t Light ... 1.5 t	Same as left		
	σ_{z0} (Car)	3 m	5 m			
	He (Car)	2 m	3 m			
	Ratio of upper layer and surface wind velocity	EPA value (10 m→2 m)	EPA value (10 m→3 m)			
	Reaction coefficient	α=0.80 β daytime=0.3 β nighttime=0.0 k=0.23	α=0.9 β=0.3 k=0.208			
	Ozone reduction under parallel wind direction	Not considered	Considered			
	S content of diesel oil	0.56% (Average of 0.46% and 0.65%)				0.46%
	Light freight-train car	Diesel cars only				Diesel and gasoline cars 3:1
	Transportation volume in the vicinity around MS5	Value measured in the field survey (24,267 Vehicles/day) was applied				Modified by the ratio of two points on the Bangna-Trat highway to 15,577 vehicles/day
Factory/vessel	Diffusion width	P-G diagram	Yamamoto/Yokoyama type	Same as left		
	Effective stack height under windy condition	Large-scale stack; Moses & Carson type Small stack; CONCAWE type	CONCAWE type			
	Reaction coefficient	α=0.8 β daytime=0.3, β nighttime=0.0 k; Point sources=0.0062 k; Area sources=0.062 k; Vessel=0.062	α=0.9 β=0.3 k is same as left.			
	Down wash	Not considered	Considered (Stack with top shade is always down-washed.)	Not considered		
	He of vessel/ferry	Vessel: 20 m; Ferry: 5 m	Same as left	Vessel; 30 m Ferry anchorage; 10 m Ferry navigation; 15 m		Vessel; 20 m Ferry; 5 m
	Area sources of He	30 m			40 m	30 m
	Parameter k of σ_{E}	A, B: 2.7 C: 1.0 D: 1.0 E: 0.83 F: 0.83			A, B: 2.67 C: 2.04 D: 1.0 E: 0.83 F: 0.83	
	S content of fuel used with vessel	2.5%; under the assumption that fuel oil is used				Less than 1,000 tonnage: 1.03% 1,000 Tonnage or greater: 2.5%
	S content of low speed diesel oil used with ferry boat	2.5%; under the assumption that low speed diesel oil is used				0.56%: under the assumption that high speed diesel oil is used
	Ferry boat horsepower	240 PS for F1, F2 and F3 courses				F1, F2; 225 PS F3 ; 200 PS

Table 1-15 Comparison of Measured and Calculated Values of Ambient SO_2, NO_2 and NO_x Concentration by Season and Time Zone

(SO_2)

(unit ; ppb)

STATION	South Wet			North Dry			South Dry			Annual		
	Day	Nig.	Ave	Day	Nig.	Ave	Day	Nig.	Ave	Day	Nig.	Ave
(MS1) ONEB STATION	6.4	7.1	6.8	5.9	11.8	9.1	4.6	5.3	4.9	5.8	7.8	6.9
	7.1	12.8	10.2	4.3	9.0	6.8	5.7	8.3	7.1	6.1	10.7	8.6
(MS2) POWER PLANT	9.3	12.9	11.3	8.5	19.7	14.7	9.7	12.8	11.4	9.2	14.6	12.2
	10.2	12.0	11.2	9.6	16.5	13.4	9.2	7.2	8.2	9.8	12.0	11.0
(MS3) MIN.DEP.OFFICE	17.1	23.5	20.6	15.9	22.6	19.6	20.9	43.3	33.1	17.7	28.3	23.5
	20.8	25.1	23.1	16.4	16.8	16.6	20.5	16.3	18.2	19.6	20.8	20.3
(MS4) S.P.PRO.OFFICE	3.6	5.1	4.4	5.3	8.7	7.1	3.8	4.1	4.0	4.0	5.7	5.0
	6.5	9.5	8.1	6.5	12.1	9.6	5.5	5.9	5.7	6.3	9.3	7.9
(MS5) H.& I. ESTATE	3.5	4.4	4.0	1.8	3.0	2.5	1.6	1.7	1.7	2.4	3.2	2.9
	1.5	2.2	1.9	2.2	2.9	2.6	1.0	1.5	1.3	1.6	2.2	1.9

(NO_2)

STATION	South Wet			North Dry			South Dry			Annual		
	Day	Nig.	Ave	Day	Nig.	Ave	Day	Nig.	Ave	Day	Nig.	Ave
(MS1) ONEB STATION	17.8	17.0	17.4	10.9	21.1	16.5	10.0	11.7	11.0	14.1	16.7	15.6
	10.9	14.8	13.0	11.8	18.4	15.4	8.4	10.4	9.5	10.5	14.6	12.7
(MS2) POWER PLANT	7.3	8.1	7.7	7.2	14.3	11.1	7.6	9.5	8.6	7.3	9.8	8.7
	5.8	9.0	7.5	4.0	8.7	6.5	5.4	6.3	5.9	5.3	8.2	6.9
(MS3) MIN.DEP.OFFICE	6.9	9.7	8.4	14.6	24.8	20.2	10.4	16.1	13.5	10.1	15.7	13.2
	9.6	9.7	9.7	8.1	7.7	7.9	9.3	6.9	8.0	9.2	8.5	8.8
(MS4) S.P.PRO.OFFICE	10.3	11.1	10.7	27.1	34.7	31.2	9.2	10.0	9.7	13.5	15.7	14.7
	10.0	11.3	10.7	11.8	18.0	15.2	8.3	7.4	7.8	10.0	12.0	11.1
(MS5) H.& I. ESTATE	3.4	5.7	4.7	4.1	8.3	6.4	3.5	5.2	4.4	3.6	6.1	5.0
	2.6	4.2	3.5	4.2	6.4	5.4	1.9	3.5	2.8	2.8	4.6	3.8

(NO_x)

STATION	South Wet			North Dry			South Dry			Annual		
	Day	Nig.	Ave	Day	Nig.	Ave	Day	Nig.	Ave	Day	Nig.	Ave
(MS1) ONEB STATION	39.7	56.4	48.8	20.3	47.7	35.3	17.2	19.9	18.7	29.2	45.1	37.9
	25.0	43.4	35.0	24.2	54.4	40.6	16.8	25.2	21.4	22.8	41.7	33.0
(MS2) POWER PLANT	16.2	16.7	16.5	15.0	24.4	20.1	17.0	18.0	17.6	16.2	18.7	17.6
	11.8	15.5	13.8	7.1	14.1	10.9	11.6	10.3	10.9	10.6	13.9	12.4
(MS3) MIN.DEP.OFFICE	14.3	20.0	17.4	25.5	44.4	35.8	19.1	26.0	22.8	18.8	28.5	24.1
	23.9	24.9	24.5	21.3	21.4	21.3	22.9	17.7	20.1	23.0	22.3	22.6
(MS4) S.P.PRO.OFFICE	24.4	28.6	26.7	49.8	71.7	61.7	25.5	25.1	25.3	29.9	36.7	33.6
	24.3	30.9	27.9	27.3	47.0	38.0	21.2	21.6	21.4	24.3	32.7	28.8
(MS5) H.& I. ESTATE	8.3	12.0	10.3	6.8	11.5	9.4	5.5	7.1	6.3	7.2	10.5	9.0
	5.3	9.1	7.4	9.7	14.0	12.0	4.0	7.2	5.8	6.1	9.9	8.1

UPPER ; observed concentration
LOWER ; calculated concentration

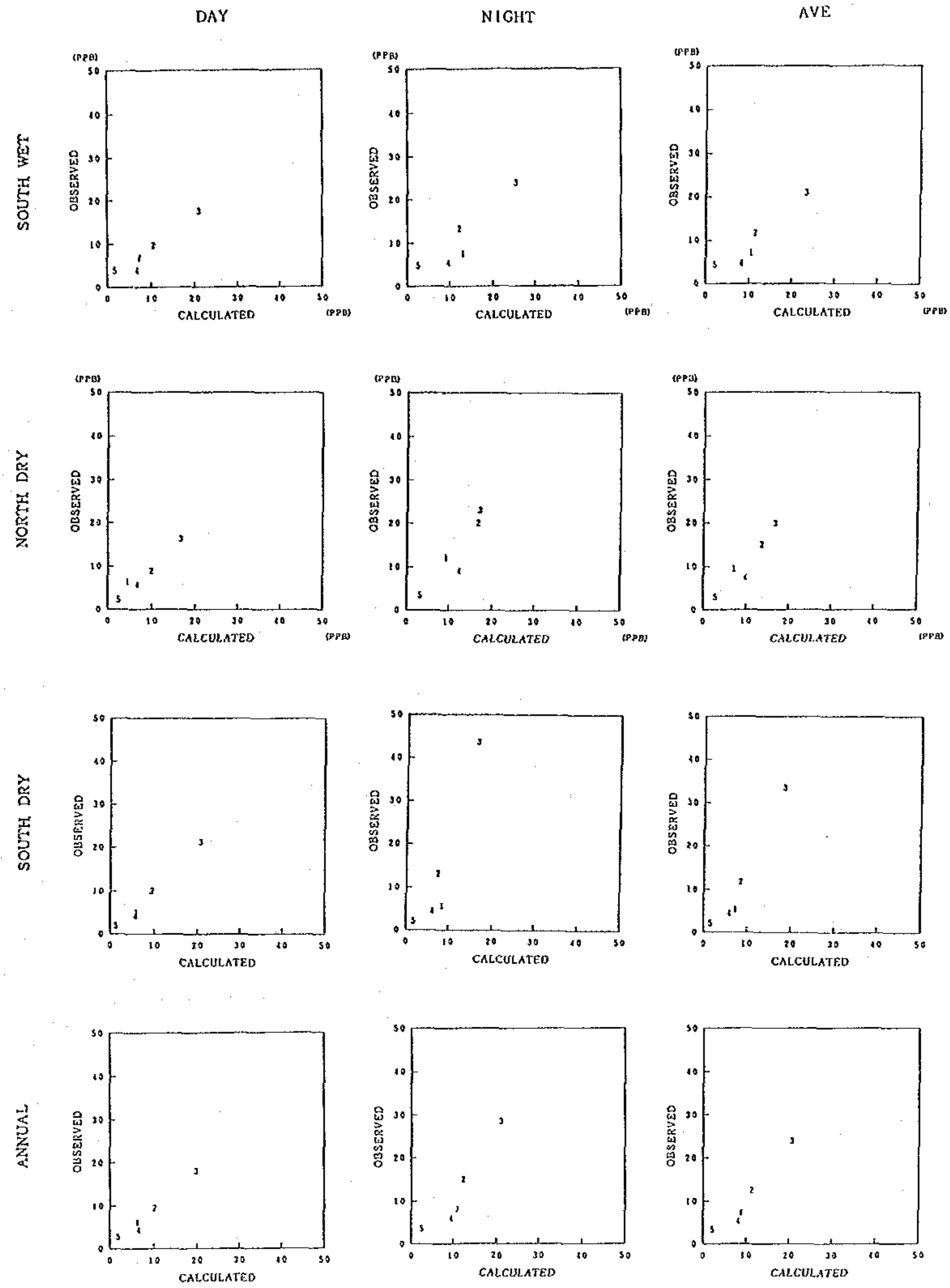


Fig. 1-20(1) Comparison of Measured and Calculated Values of SO_2 Ambient Concentration

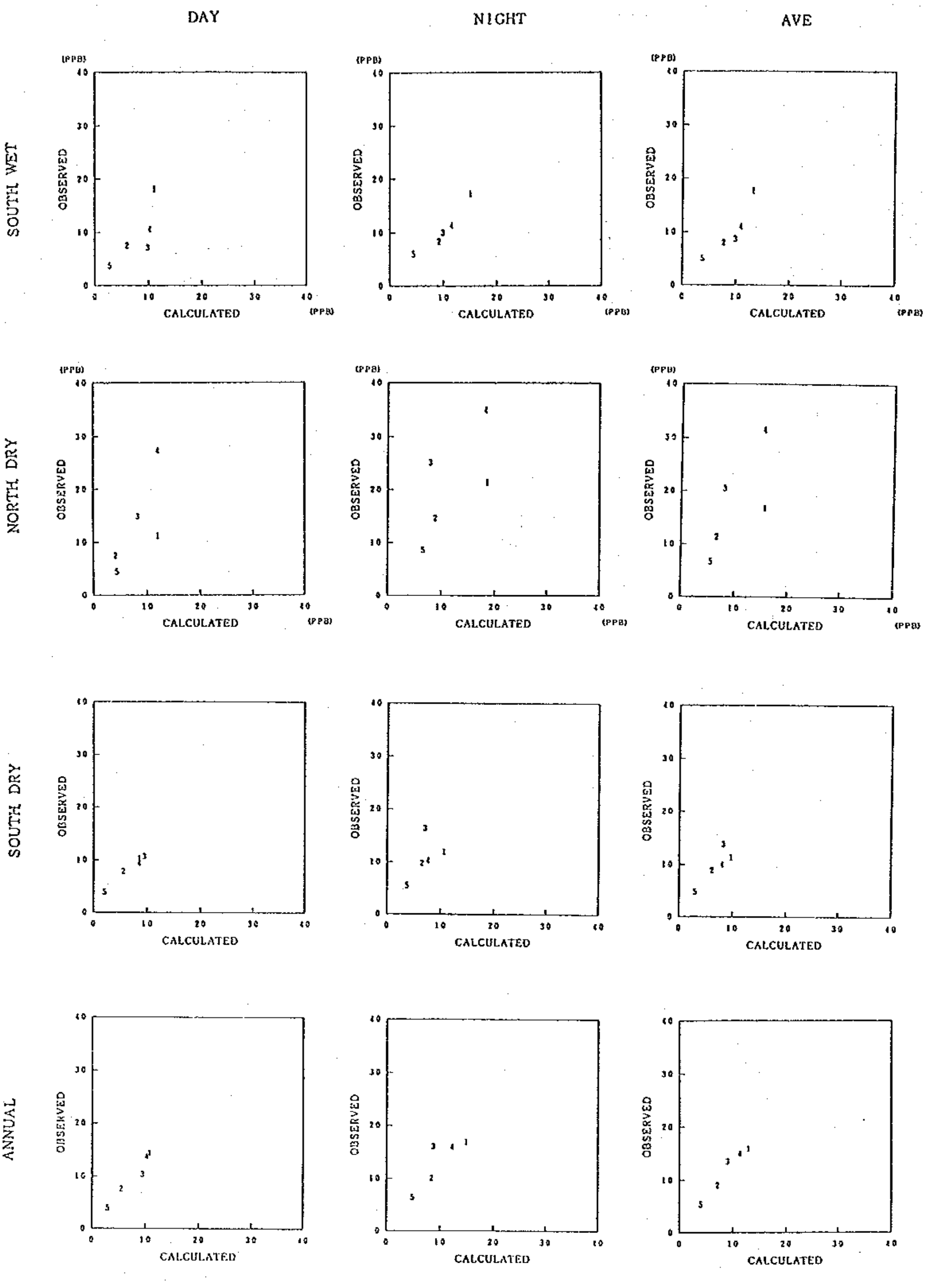


Fig. 1-20(2) Comparison of Measured and Calculated Values of NO_2 Ambient Concentration

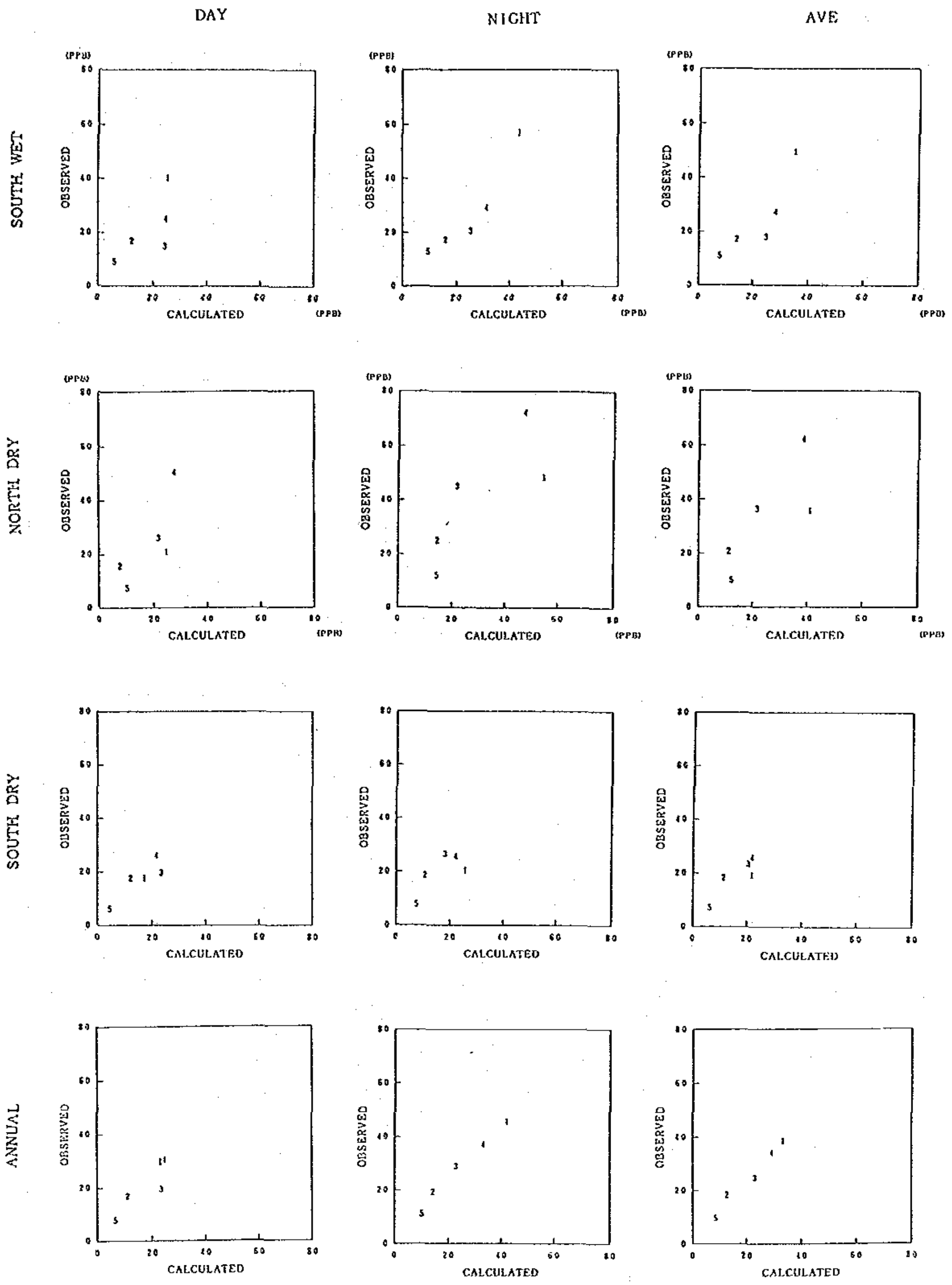


Fig. 1-20(3) Comparison of Measured and Calculated Values of NO_x Ambient Concentration

Table 1-16 Evaluation of Agreement of Ambient Pollutant Concentration Simulation Model

[SO_2]

Season and time zone		Ave.of obs. Y (ppb)	Ave.of cal. X (ppb)	A_0 (Y-X) (ppb)	Regression equation	Corr. coef.	Vari. coef.	Rank
South Wet	Day	7.9	9.2	-1.3	Y = 0.760X + 1.0	0.969	0.25	B
	Night	10.6	12.3	-1.7	Y = 0.881X - 0.3	0.914	0.29	C
	Ave.	9.4	10.9	-1.5	Y = 0.846X + 0.2	0.947	0.24	A
North Dry	Day	7.5	7.8	-0.3	Y = 0.936X + 0.2	0.978	0.14	A
	Night	13.2	11.5	1.7	Y = 1.272X - 1.4	0.922	0.24	B
	Ave.	10.6	9.8	0.8	Y = 1.162X - 0.8	0.957	0.18	A
South Dry	Day	8.1	8.4	-0.3	Y = 1.039X - 0.6	0.991	0.12	A
	Night	13.4	7.8	5.6	Y = 2.949X - 9.7	0.922	0.83	–
	Ave.	11.0	8.1	2.9	Y = 1.994X - 5.1	0.966	0.57	–
Annual	Day	7.8	8.7	-0.8	Y = 0.885X + 0.2	0.987	0.14	A
	Night	11.9	11.0	0.9	Y = 1.412X - 3.6	0.936	0.33	C
	Ave.	10.1	9.9	0.1	Y = 1.197X - 1.8	0.968	0.22	A

[NO_2]

Season and time zone		Ave.of obs. Y (ppb)	Ave.of cal. X (ppb)	A_0 (Y-X) (ppb)	Regression equation	Corr. coef.	Vari. coef.	Rank
South Wet	Day	9.1	7.8	1.4	Y = 1.203X - 0.2	0.776	0.34	–
	Night	10.3	9.8	0.5	Y = 1.052X + 0.0	0.953	0.11	A
	Ave.	9.8	8.9	0.9	Y = 1.197X - 0.8	0.908	0.19	A
North Dry	Day	12.8	8.0	4.8	Y = 1.741X - 1.1	0.750	0.46	–
	Night	20.6	11.8	8.8	Y = 1.155X + 7.0	0.677	0.32	C
	Ave.	17.1	10.1	7.0	Y = 1.426X + 2.7	0.729	0.36	–
South Dry	Day	8.1	6.7	1.5	Y = 0.912X + 2.1	0.989	0.05	A
	Night	10.5	6.9	3.6	Y = 0.946X + 4.0	0.586	0.27	C
	Ave.	9.4	6.8	2.6	Y = 1.131X + 1.8	0.872	0.16	A
Annual	Day	9.7	7.6	2.2	Y = 1.272X + 0.1	0.974	0.13	A
	Night	12.8	9.6	3.2	Y = 1.032X + 2.9	0.856	0.17	A
	Ave.	11.4	8.7	2.8	Y = 1.238X + 0.7	0.976	0.10	A

[NO_x]

Season and time zone		Ave.of obs. Y (ppb)	Ave.of cal. X (ppb)	A_0 (Y-X) (ppb)	Regression equation	Corr. coef.	Vari. coef.	Rank
South Wet	Day	20.6	18.1	2.5	Y = 0.942X + 3.6	0.696	0.38	–
	Night	26.7	24.8	2.0	Y = 1.238X - 3.9	0.939	0.23	B
	Ave.	23.9	21.7	2.3	Y = 1.192X - 1.9	0.874	0.28	C
North Dry	Day	23.5	17.9	5.5	Y = 1.432X - 2.2	0.793	0.41	–
	Night	39.9	30.2	9.8	Y = 0.948X +11.3	0.786	0.32	C
	Ave.	32.5	24.6	7.9	Y = 1.119X + 5.0	0.797	0.33	C
South Dry	Day	16.8	15.3	1.5	Y = 0.830X + 4.1	0.883	0.19	A
	Night	19.2	16.4	2.8	Y = 0.719X + 7.4	0.716	0.27	C
	Ave.	18.1	15.9	2.2	Y = 0.896X + 3.9	0.881	0.17	A
Annual	Day	20.2	17.4	2.9	Y = 0.999X + 2.9	0.882	0.20	A
	Night	27.9	24.1	3.8	Y = 1.035X + 3.0	0.989	0.07	A
	Ave.	24.4	21.0	3.5	Y = 1.094X + 1.5	0.988	0.08	A

(2) Contribution Rate by Source at Monitoring Station

The measured values at each station are as shown in Table 1-15. The contribution rate by source (factory, car, vessel and ferry) was calculated while accounting for the background concentration.

The difference between the average y of the measured concentration and the average x of the calculated concentration at each monitoring station is as shown in Table 1-16. The difference is thought due to the following causes.

① Pollutants emitted from sources in the target area or in adjacent area are made blown back by circulating sea or land breeze or due to change of wind direction.

② Pollutants emitted from middle/small sources or moving sources which cannot be detected in the target area or in adjacent area.

③ Pollutants long-term staying in the ambient air

④ Measurement error at monitoring station

⑤ Adsorption of pollutants to ground surface

⑥ Decomposition of pollutants in atmosphere

⑦ Background concentration from natural sources

In this study, this $\bar{y}-\bar{x}$ was added to the calculated value as background concentration. Table 1-17 shows the contributing concentrations and their contribution rate by source to yearly average concentration of each monitoring station while the background concentration is taken into consideration.

The significant contribution of the sources to SO_2 concentration were found in small factories having the stacks less than 50 m high and in automobiles. The sizable plants with stacks more than 50 m high have small contribution less than 10 pct at most. As for NO_2, the largest contributer is automobiles and next comes ships. The factories large and small combined have contribution of 10 pct or so.

Table 1-17 Contribution Concentration by Source at Monitoring Station

SO_2

Station	Observed conc.	yearly average concentration and ratio for each source																		
		Total	Stationary (point) H_0 ≥50m		Stationary (point) H_0 <50m		Stationary (area)		Roadways		Vessels sailing		Ferryboats anchoring		Ferryboats sailing		Back ground	
	(ppb)	(ppb)	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%
(MS1) ONEB STATION	6.9	8.7	0.25	3	2.27	26	2.08	24	3.76	43	0.25	3	0.00	0	0.00	0	0.1	1
(MS2) POWER PLANT	12.2	11.1	1.01	9	3.97	36	3.68	33	0.95	9	1.35	12	0.00	0	0.01	0	0.1	1
(MS3) MIN.DEP.OFFICE	23.5	20.4	0.47	2	10.14	50	4.26	21	0.85	4	3.22	16	0.10	1	1.22	6	0.1	0
(MS4) S.P.PRO.OFFICE	5.0	8.0	0.07	1	2.00	25	1.55	19	3.46	43	0.82	10	0.00	0	0.00	0	0.1	1
(MS5) H. & I. ESTATE	2.9	2.0	0.01	0	0.32	16	0.42	21	1.14	57	0.01	0	0.00	0	0.00	0	0.1	5

NO_2

Station	Observed conc.	yearly average concentration and ratio for each source																		
		Total	Stationary (point) H_0 ≥50m		Stationary (point) H_0 <50m		Stationary (area)		Roadways		Vessels sailing		Ferryboats anchoring		Ferryboats sailing		Back ground	
	(ppb)	(ppb)	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%
(MS1) ONEB STATION	15.6	15.5	0.18	1	0.09	1	0.17	1	12.00	77	0.29	2	0.00	0	0.01	0	2.8	18
(MS2) POWER PLANT	8.7	9.7	0.20	2	0.13	1	0.35	4	5.27	54	0.86	9	0.01	0	0.05	1	2.8	29
(MS3) MIN.DEP.OFFICE	13.2	11.6	0.30	3	0.25	2	0.57	5	4.08	35	1.72	15	0.15	1	1.74	15	2.8	24
(MS4) S.P.PRO.OFFICE	14.7	13.9	0.04	0	0.09	1	0.12	1	10.25	74	0.60	4	0.00	0	0.01	0	2.8	20
(MS5) H. & I. ESTATE	5.0	6.6	0.01	0	0.02	0	0.02	0	3.71	57	0.01	0	0.00	0	0.00	0	2.8	43

NO_x

Station	Observed conc.	yearly average concentration and ratio for each source																		
		Total	Stationary (point) H_0 ≥50m		Stationary (point) H_0 <50m		Stationary (area)		Roadways		Vessels sailing		Ferryboats anchoring		Ferryboats sailing		Back ground	
	(ppb)	(ppb)	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%	(ppb)	%
(MS1) ONEB STATION	37.9	36.5	0.63	2	0.41	1	0.30	1	31.22	85	0.44	1	0.00	0	0.01	0	3.5	10
(MS2) POWER PLANT	17.6	15.9	1.42	9	0.66	4	0.72	5	7.06	45	2.42	15	0.01	0	0.07	0	3.5	22
(MS3) MIN.DEP.OFFICE	24.1	26.1	1.24	5	1.55	6	1.14	4	6.12	24	5.77	22	0.46	2	6.33	24	3.5	13
(MS4) S.P.PRO.OFFICE	33.6	32.3	0.18	1	0.42	1	0.22	1	26.54	82	1.46	4	0.00	0	0.01	0	3.5	11
(MS5) H. & I. ESTATE	9.0	11.6	0.02	0	0.08	1	0.05	0	7.97	69	0.01	0	0.00	0	0.00	0	3.5	30

1.3 Estimation of Ambient Pollutant Concentrations for Whole Area and Contribution Rate by Source by Using Atmospheric Diffusion Simulation Model

With the atmospheric pollutant sources and meteorological condition of 1988 as input data, SO_2, NO_2 and NO_x environmental concentrations were calculated by season, by time zone and by yearly period for the whole Samut Prakarn province (1 km×km mesh). As for the SO_2 and NO_2 yearly average values, the contribution rate by source to points with significant concentration level was calculated.

1.3.1 SO_2, NO_2 and NO_x Concentrations in whole Samut Prakarn Province

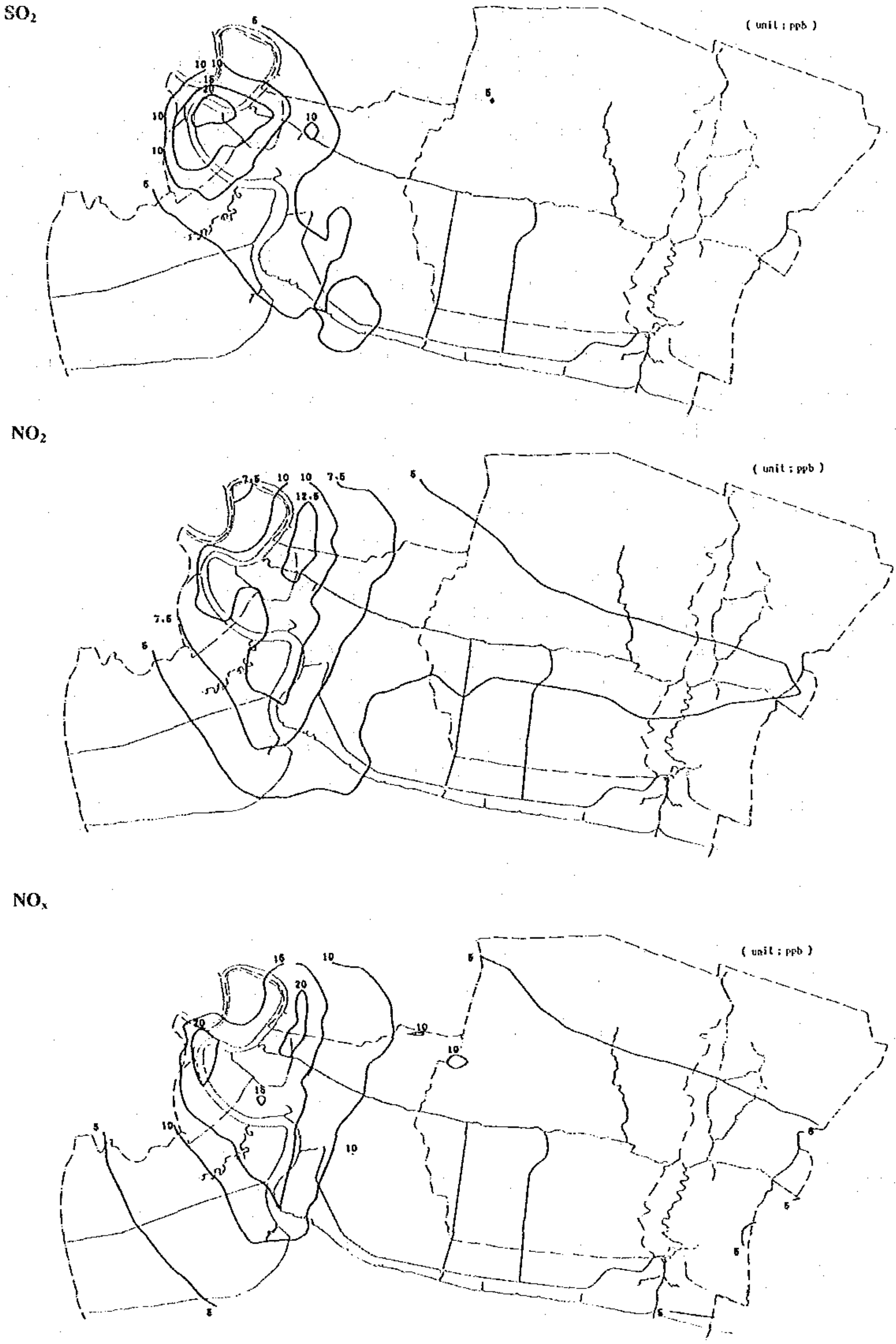
Fig. 1-21 shows the yearly average concentrations by season and by time zone in the whole Samut Prakarn province in 1988 expressed as a topograhic diagram. This calculated value includes background concentration.

1.3.2 Comparison with Environmental Standards

The yearly average concentrations in the whole area and the environmental standard were compared. For the environmental standard in Thailand, SO_2 is determined by daily average value and geometric yearly average value, and NO_2 is determined by one-hour average value. However, the calculated value of ambient pollutant concentration is the yearly average value, and so it is necessary for calculated value and the environmental standard value to be compared on the same conditions. In this study, the relationship of the yearly average of the measured values in each monitoring station, the daily average value of SO_2 and one-hour value of NO_2 were expressed by linear regression equation of the first order. Then, the yearly average value calculated from this line was converted to the equivalent daily average or one-hour average value, which was then compared with the environmental standards.

Fig. 1-22 shows the relationship between the yearly and max. of daily average values of SO_2 and the relationship between the yearly and max. of one-hour average values of NO_2. In this figure, if the yearly average value of SO_2 exceeds 42 ppb, or if the yearly average value of NO_2 exceeds 18 ppb, the environmental standards will be violate.

Fig. 1-23 shows the calculation results of SO_2, NO_2 and NO_x yearly averages. Table 1-18 shows number of meshes by rank of concentration. From the table, both SO_2 and NO_2 concentrations are found satisfying the environmental standards across the whole Samut Prakarn Province.


SO₂

NO₂

NOₓ

Fig. 1-21 Yearly Average Ambient Pollutant Concentrations in the Samut Prakarn Province in 1988

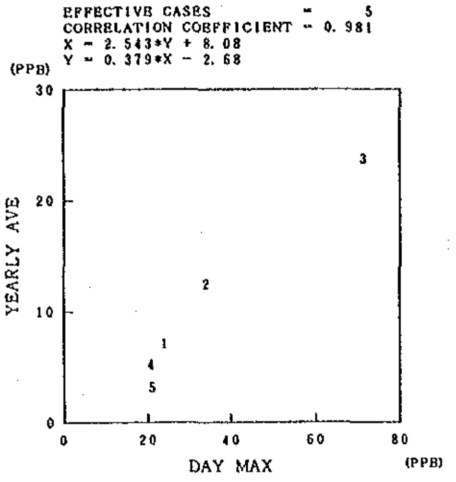


Fig. 1-22(1) Relationship between SO$_2$ Yearly Average Concentration and Max. of Daily Average Concentration

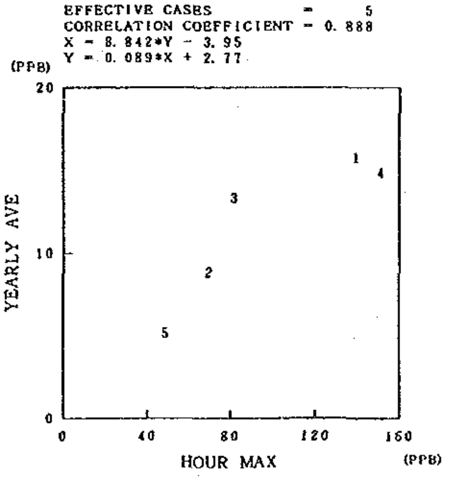


Fig. 1-22(2) Relationship between NO$_2$ Yearly Average Concentration and Max. of One-hour Average Concentration

Table 1-18 Number of Meshes by Rank of Concentration

(SO$_2$)

Rank of cocentration (ppb)	Number of mesh
0.0 ~ 5.0	977
5.0 ~ 10.0	128
10.0 ~ 15.0	28
15.0 ~ 20.0	21
20.0 ~ 25.0	5
TOTAL	1159

(NO$_2$)

Rank of cocentration (ppb)	Number of mesh
0.0 ~ 5.0	674
5.0 ~ 7.5	306
7.5 ~ 10.0	109
10.0 ~ 12.5	64
12.5 ~ 15.0	7
TOTAL	1159

(NOx)

Rank of cocentration (ppb)	Number of mesh
0.0 ~ 5.0	277
5.0 ~ 10.0	676
10.0 ~ 15.0	116
15.0 ~ 20.0	79
20.0 ~ 25.0	9
25.0 ~ 30.0	2
TOTAL	1159

(unit ; 0.1 ppb)

	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)	15)	16)	17)	18)	19)	20)	21)	22)	23)	24)	25)	26)	27)	28)	29)	30)	31)	32)	33)	34)	35)	36)	37)	38)	39)	40)	41)	42)	43)	44)	45)	46)	47)	48)	49)	50)	51)	52)	53)	54)	55)	56)	57)	58)	59)	60)	61)
30)																														8	7	7	6	5	5	4	4	3	3	3																	
29)													61	59	54	48	42	36	32	25	23	21	18	16	14	12	11	10	9	8	8	8	7	6	5	5	4	4	3	3	3	3	3														
28)													72	63	61	63	51	44	36	28	26	24	20	17	15	13	12	11	10	9	9	9	8	6	6	5	5	4	4	3	3	3	3	3	2	2	2	2									
27)													91	75	67	69	61	52	42	33	30	27	23	19	17	15	14	12	11	10	10	10	8	7	6	5	5	5	4	4	4	3	3	3	3	2	2	3	2	2							
26)									65	75	86	107	108	91	82	85	68	60	47	39	34	30	25	21	19	17	15	14	13	12	11	10	9	8	7	6	5	5	5	4	4	4	3	3	3	2	3	3	3	2	2	2	2				
25)									71	95	124	150	140	121	111	102	84	70	54	42	36	31	27	23	24	21	18	16	15	14	16	12	10	8	7	6	6	6	5	5	4	4	4	3	3	3	3	3	3	2	2	2	2	2	2	2	
24)									94	114	177	229	204	179	154	130	108	84	66	48	39	33	28	24	24	24	21	18	17	17	55	14	11	9	8	7	7	6	6	5	5	5	4	4	4	3	3	3	3	3	3	2	2	2	2	2	
23)									100	165	208	225	219	196	171	175	112	86	80	55	42	32	28	25	24	23	21	20	19	20	19	15	13	10	9	8	7	7	6	6	5	5	5	4	4	4	4	3	3	3	3	3	2	2	2	2	
22)									95	189	197	176	180	180	157	120	91	82	121	69	46	32	29	27	24	22	22	21	21	21	19	17	14	12	10	9	8	8	7	7	6	5	5	5	4	4	4	4	3	3	3	3	2	2	2	2	2
21)									104	185	190	155	151	151	132	97	86	79	86	65	41	30	27	25	24	22	21	21	22	23	20	18	16	15	13	11	10	10	9	8	7	6	6	5	5	4	4	4	4	3	3	3	3	2	2	2	2
20)									93	164	178	159	128	121	104	82	79	64	59	48	37	29	26	23	23	23	21	20	23	26	22	20	18	20	15	12	13	14	12	9	8	7	6	6	5	5	4	4	4	4	3	3	3	2	2	2	
19)									80	134	138	132	114	104	96	86	78	54	46	41	35	29	25	23	23	27	22	20	24	25	22	21	20	23	15	14	18	28	17	12	10	8	7	7	6	6	5	5	4	4	4	3	3	2	2		
18)		11	13	16	20	25	34	45	68	94	100	120	102	90	93	80	65	49	43	39	36	30	25	22	24	26	22	20	22	24	23	22	20	18	16	17	30	33	18	22	11	9	9	8	8	7	6	5	5	4	4	3	3	3			
17)		11	13	16	20	24	31	39	54	69	79	91	88	81	87	81	62	48	44	44	45	34	26	21	21	22	20	18	19	20	19	18	17	15	15	17	21	20	17	16	13	11	11	12	10	9	8	7	7	6	5	4	3				
16)	9	11	13	15	19	23	28	34	43	51	60	69	73	72	76	77	62	50	46	47	74	34	24	21	19	19	17	16	16	16	15	15	13	12	13	13	16	17	16	15	14	12	14	16	13	11	10	9	8	7	6	5					
15)	9	11	13	15	18	21	25	30	36	42	49	55	60	66	70	74	66	57	51	48	68	27	24	21	19	18	16	15	14	14	13	12	11	10	11	11	12	13	12	12	11	11	12	13	11	9	9	9	8	7	6	5					
14)	9	10	12	14	17	19	23	26	31	35	39	43	51	63	66	73	85	72	61	53	54	33	26	23	20	17	15	14	12	11	10	10	9	9	9	9	9	10	10	9	9	10	10	10	9	8	8	8	7	7	7	6					
13)	9	10	12	13	16	18	21	24	27	30	34	37	44	52	60	72	83	92	78	51	46	39	33	27	21	17	15	13	12	10	10	9	8	8	8	8	8	8	8	8	8	8	8	8	7	7	6	6	6	6	5	5					
12)	9	10	11	13	15	17	19	21	24	26	29	32	38	45	56	69	71	58	61	50	48	52	41	30	23	18	15	13	11	10	9	8	8	7	7	7	7	7	7	7	7	7	7	6	6	6	5	5	5	4	4	4					
11)	8	9	11	12	13	15	17	19	21	23	26	28	33	39	46	58	74	73	53	48	61	91	49	37	27	19	16	13	11	10	9	8	7	7	7	7	7	6	6	6	6	6	6	6	5	5	4	4									
10)	8	9	10	11	12	14	16	17	19	21	23	25	29	33	36	43	55	61	50	50	97	97	59	43	31	22	17	13	11	10	9	8	7	7	7	6	6	6	6	6	6	6	5	5	5	4	4	4									
9)		8	9	10	12	13	14	16	17	19	21	23	25	28	31	35	41	45	45	51	91	60	61	39	31	31	18	13	12	15	11	8	8	7	7	7	6	6	6	6	6	6	6	5	5	4	4	4									
8)		8	9	10	11	12	13	14	15	17	18	20	22	24	26	28	31	33	42	57	72	61	44	38	24	38	13	12	15	48	12	9	9	9	8	7	7	7	7	7	7	6	6	5	5	4	4										
7)		7	8	9	10	11	12	13	14	15	17	18	19	21	22	24	26	29	35	44	49	46	38	29	27	27	13	11	16	17	10	9	9	15	8	7	6	6	6	6	6	6	6	5	5	5	4										
6)		7	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	24	27	31	33	32	28	24	22	20	14	11	10	9	8	8	11	18	8	6	6	5	5	5	5	5	5	5	5	5	5										
5)																																				5	5	4	4	4	4	4	4	4	4	4	4										
4)																																										3	3	3	3												

Fig. 1-23(1) SO_2 Concentration Distribution in Samut Prakarn Province in 1988

(unit : 0.1 ppb)

	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)	15)	16)	17)	18)	19)	20)	21)	22)	23)	24)	25)	26)	27)	28)	29)	30)	31)	32)	33)	34)	35)	36)	37)	38)	39)	40)	41)	42)	43)	44)	45)	46)	47)	48)	49)	50)	51)	52)	53)	54)	55)	56)	57)	58)	59)	60)	61)
30)																														37	37	36	34	32	30	29	29	29	29	29																	
29)													68	72	82	94	104	101	92	74	72	70	63	56	52	48	46	44	41	39	38	37	35	33	32	31	30	30	29	29	29	28	28														
28)													74	77	88	105	115	120	100	80	79	78	70	61	56	51	49	46	44	41	40	38	36	35	34	33	32	31	30	29	29	28	28	28	28	28	28	28									
27)													81	83	91	109	119	137	112	89	88	87	77	66	61	55	52	50	47	44	42	40	38	36	35	34	33	32	31	30	30	30	30	29	29	28	28	28	28	28							
26)									79	81	83	88	88	89	97	112	123	143	108	99	97	96	84	72	65	58	56	54	51	48	45	42	40	38	37	36	35	34	33	32	32	32	31	30	29	28	28	28	28	28	28	28	28				
25)									84	90	99	98	94	96	104	113	128	138	105	94	96	94	82	71	68	65	62	60	56	51	48	45	42	40	39	37	37	36	35	34	34	34	33	32	31	31	31	30	30	30	30	30	29	29	29	28	
24)									86	86	124	107	105	108	110	115	136	133	106	98	95	92	81	70	71	71	69	66	61	55	51	47	44	42	41	39	39	38	37	36	36	36	35	34	34	33	33	32	32	32	31	31	30	30	29	28	
23)									84	92	119	109	110	109	112	124	134	108	101	93	89	84	76	68	68	68	69	69	65	61	56	50	48	45	43	42	41	40	39	38	38	37	36	36	35	35	34	34	33	33	32	32	31	30	30	29	
22)									82	93	114	103	100	99	102	118	120	104	98	93	84	75	70	66	65	65	69	73	69	66	60	54	51	48	46	44	43	42	41	40	39	39	38	37	37	36	36	35	34	33	33	32	32	31	30	30	29
21)									81	99	106	102	99	97	101	112	103	100	90	90	81	73	69	65	63	62	66	69	67	65	61	56	54	53	51	49	47	45	44	43	42	41	40	40	39	38	37	36	36	35	34	33	32	32	31	30	29
20)									74	96	98	101	99	96	100	104	112	106	94	84	78	72	68	64	61	59	62	66	65	65	61	58	58	58	55	53	51	49	47	46	44	43	43	42	41	40	39	38	37	36	35	34	33	32	31	30	
19)									69	85	98	95	97	97	100	111	114	101	89	79	74	68	64	61	59	57	60	63	62	61	60	58	59	60	58	57	55	54	53	52	50	48	47	46	45	43	42	40	39	38	37	36	34	33	32		
18)		34	35	37	40	43	49	55	65	76	86	96	98	100	109	118	105	92	83	74	70	65	61	58	56	54	57	60	59	57	58	58	60	62	61	60	60	59	58	58	55	52	51	50	48	47	45	43	41	40	38	37	35	33			
17)		33	35	37	40	42	48	53	61	69	78	88	96	104	109	114	102	89	79	70	66	61	58	55	54	52	55	57	56	54	53	55	57	58	58	58	59	59	60	60	59	57	56	55	54	52	50	48	46	45	42	40	38				
16)	31	32	34	36	39	42	46	51	57	63	71	79	93	107	108	110	98	86	76	66	63	57	54	52	51	50	52	54	53	51	52	52	53	54	55	56	58	59	61	63	62	61	61	61	60	58	56	53	51	49	47	44					
15)	31	31	33	35	38	40	44	48	53	58	65	72	86	99	102	105	92	79	70	62	58	52	51	49	49	48	50	52	50	49	47	49	50	51	51	52	53	55	57	59	58	58	58	58	57	55	54	53	51	50	48	46					
14)	31	31	33	34	36	39	42	45	50	54	60	66	78	91	95	99	86	73	65	58	53	48	47	47	47	46	48	49	48	46	46	46	47	47	48	48	49	50	53	55	55	55	55	55	54	52	52	52	52	51	50	48					
13)	31	31	32	33	35	38	40	43	47	51	56	61	74	86	88	91	80	68	62	56	52	47	46	45	45	44	46	47	46	45	45	45	45	45	46	47	48	48	50	51	52	52	51	51	50	48	48	47	46	46	44	43					
12)	31	31	31	32	34	37	39	41	44	48	52	57	69	81	82	82	73	63	59	54	50	46	44	43	42	42	43	45	44	43	43	43	44	44	44	45	46	46	47	48	48	48	48	47	46	44	43	42	41	40	39						
11)	31	31	31	32	33	35	37	40	43	46	50	54	64	74	72	71	66	60	57	54	51	48	45	44	43	42	43	44	43	43	43	43	43	43	44	44	45	46	47	47	47	47	46	46	44	43	41	40									
10)	30	31	31	31	32	33	35	38	41	43	48	52	59	66	63	61	59	57	55	54	52	49	47	45	43	42	43	43	43	42	42	43	43	43	43	44	45	46	46	47	46	46	45	44	43	41	40	39									
9)		31	31	31	32	33	34	36	39	41	45	49	53	58	57	56	54	53	52	52	50	47	46	44	43	42	44	45	45	45	45	45	44	44	45	45	46	48	48	48	48	48	47	45	43	41	40	38									
8)		31	31	31	32	32	33	34	36	38	42	45	48	50	51	51	50	49	49	50	49	46	45	43	43	43	45	47	47	48	47	47	46	46	46	46	48	49	49	49	49	50	48	46	44	42	40										
7)		30	31	31	31	32	33	34	35	37	39	42	44	45	46	47	46	45	46	46	45	43	42	41	41	41	42	44	45	45	45	46	45	46	45	45	46	46	46	46	46	47	46	46	44	43	41										
6)		30	31	31	31	31	32	33	34	35	37	38	39	40	41	42	42	42	42	42	41	40	39	38	39	39	40	41	42	43	44	44	45	45	45	45	44	43	43	43	43	44	44	45	44	44	42										
5)																																				41	40	40	39	39	40	40	41	41	41	41	39										
4)																																										36	37	37	38												

Fig. 1-23(2) NO_2 Concentration Distribution in Samut Prakarn Province in 1988

(unit ; 0.1 ppb)

	5)	6)	7)	8)	9)	10)	11)	12)	13)	14)	15)	16)	17)	18)	19)	20)	21)	22)	23)	24)	25)	26)	27)	28)	29)	30)	31)	32)	33)	34)	35)	36)	37)	38)	39)	40)	41)	42)	43)	44)	45)	46)	47)	48)	49)	50)	51)	52)	53)	54)	55)	56)	57)	58)	59)	60)	61)
30)																														48	47	46	43	40	39	37	37	36	36	36																	
29)													115	121	128	139	153	148	133	100	97	94	84	74	68	61	59	56	53	50	49	48	45	42	41	39	38	38	37	36	36	36	36													
28)													119	116	134	168	169	176	146	110	109	108	94	81	73	66	62	59	56	53	51	50	47	44	43	41	40	39	37	36	36	36	36	36	36	36	35	35									
27)													132	123	134	166	180	205	165	125	124	121	105	89	80	71	67	64	61	57	55	52	49	46	45	43	42	41	40	38	38	38	37	37	36	36	36	36	35	35							
26)									133	131	130	145	142	133	144	178	182	217	161	144	139	135	116	97	86	76	72	69	66	62	60	55	52	49	47	45	44	43	42	41	40	40	39	38	37	36	36	36	35	35	35	35	35				
25)									133	153	177	174	152	150	165	176	190	208	156	135	137	134	116	98	93	88	83	79	73	68	65	58	54	51	49	47	46	45	44	43	43	42	41	40	39	39	38	38	38	37	37	37	37	36	36	35	
24)									138	146	294	203	185	184	185	175	208	201	155	138	135	132	116	100	100	100	94	89	81	75	72	60	57	54	52	50	49	48	46	45	45	45	44	43	42	42	41	41	40	40	39	39	38	37	36	35	
23)									134	164	261	197	199	186	180	196	208	164	147	127	125	117	105	93	94	95	96	96	90	85	75	66	61	57	55	53	52	50	49	48	47	47	46	45	44	43	43	42	42	41	40	40	39	38	37	36	
22)									130	165	230	185	180	167	165	182	184	155	144	130	116	102	94	87	88	90	97	103	99	95	83	71	66	61	59	57	55	53	52	51	50	49	48	47	46	45	45	44	43	42	41	41	40	39	38	37	37
21)									129	173	202	181	177	161	157	171	157	147	130	129	112	100	93	86	85	84	90	96	94	93	85	77	74	71	67	63	61	58	56	54	53	52	51	50	49	48	47	46	45	44	43	42	41	39	39	38	37
20)									114	168	177	183	172	154	149	154	165	151	131	118	108	99	92	86	82	78	83	88	90	91	87	82	82	81	76	70	67	63	61	58	56	55	54	53	52	51	49	47	46	45	44	43	42	40	39	38	
19)									104	143	168	161	167	154	152	170	171	143	122	109	101	93	87	82	78	76	80	85	85	84	82	80	83	85	81	78	76	75	73	69	65	62	60	58	57	55	53	51	49	48	46	45	43	41	40		
18)		44	46	49	53	58	68	77	98	118	138	159	156	158	171	183	157	131	116	102	95	87	82	78	75	73	77	81	79	77	78	79	83	88	86	85	86	87	83	82	74	69	66	64	63	59	57	54	52	50	48	46	44	42			
17)		43	46	49	53	58	66	74	89	104	121	139	151	162	171	178	153	128	112	98	94	83	77	72	71	69	72	76	74	72	73	74	77	79	80	80	82	83	84	85	81	77	76	75	73	70	67	64	61	58	55	52	48				
16)	40	42	45	48	53	57	64	71	81	91	105	120	144	167	170	172	149	126	109	94	100	77	71	67	66	65	67	70	69	67	68	69	70	71	73	75	78	80	85	89	87	84	85	86	83	81	77	74	70	66	62	57					
15)	40	41	44	47	51	55	61	67	76	84	96	108	130	152	159	166	142	117	102	88	91	69	66	64	63	62	65	67	65	63	63	64	64	65	67	68	70	72	76	80	79	78	79	79	77	75	74	72	70	68	65	61					
14)	40	41	43	45	49	53	58	63	70	78	87	96	117	137	148	159	135	109	96	85	80	66	63	62	61	60	62	64	61	58	59	59	59	60	60	61	63	64	68	72	72	72	72	72	71	69	70	70	70	70	68	66					
13)	40	41	42	44	48	51	56	60	66	72	81	89	109	129	141	153	129	105	93	81	74	65	62	59	58	57	59	61	59	57	57	57	57	57	58	59	60	61	64	66	67	67	66	66	64	62	62	62	61	61	59	57					
12)	40	41	41	42	46	50	53	57	62	67	74	81	101	121	133	146	121	94	87	78	72	65	61	57	55	55	56	58	56	55	55	55	55	55	56	57	58	58	60	61	61	62	61	60	58	56	54	53	52	51	49						
11)	40	40	41	42	45	47	51	54	59	64	70	77	93	109	113	119	109	98	88	80	75	73	64	59	57	55	56	57	56	54	54	55	55	55	55	56	57	58	59	60	60	60	59	58	56	54	52	51									
10)	40	40	41	42	43	45	48	52	56	60	66	72	84	97	93	90	95	100	90	82	81	77	67	62	59	56	56	56	55	54	54	54	54	54	55	55	57	58	59	60	59	58	57	56	54	52	50	49									
9)		40	41	41	43	44	46	49	53	56	61	67	75	83	82	80	82	84	84	84	81	70	67	62	60	59	59	61	60	60	60	59	58	58	58	58	60	62	63	63	63	63	61	58	55	52	50	48									
8)		40	40	41	42	43	45	46	49	52	57	61	66	70	70	71	70	69	77	87	79	69	65	64	60	62	62	65	66	74	65	64	62	61	61	60	63	66	67	67	68	68	64	61	57	53	50										
7)		40	40	41	41	42	44	45	47	49	53	56	59	62	63	64	63	63	67	72	67	61	59	56	56	56	57	60	62	63	62	62	62	63	61	60	61	61	61	61	62	63	62	61	59	57	54										
6)		39	40	40	41	41	43	44	45	47	49	51	53	54	56	57	57	56	57	58	56	54	53	51	51	51	53	55	56	57	59	61	62	64	61	60	59	57	56	55	57	58	60	61	61	61	57										
5)																																				54	53	51	51	50	51	52	53	54	55	55	51										
4)																																										46	47	47	49												

Fig. 1-23(3) NO_x Concentration Distribution in Samut Prakarn Province in 1988

1.3.3 Estimation of Contribution Rate by Source

Because both SO_2 and NO_2 concentrations are found to meet the environmental standards at Samut Prakarn, top eight points that have high concentration are selected and the contribution rates of SO_2 and NO_2 yearly average concentrations by source at these points are calculated. The eight selected points are as shown in Table 1-19 and in Fig. 1-24.

Table 1-19 High Cocentration Point and Yearly Average Concentrations of SO_2 and NO_2

(SO_2)

SEQ)	Mesh IX — Mesh IY	yearly average concentration (ppb)
1)	16 — 24	22. 9
2)	16 — 23	22. 6
3)	17 — 23	21. 9
4)	15 — 23	20. 8
5)	17 — 24	20. 4
6)	15 — 22	19. 7
7)	18 — 23	19. 6
8)	15 — 21	19. 0

(NO_2)

SEQ)	Mesh IX — Mesh IY	yearly average concentration (ppb)
1)	22 — 26	14. 3
2)	22 — 25	13. 8
3)	22 — 27	13. 7
4)	21 — 24	13. 6
5)	21 — 23	13. 4
6)	22 — 24	13. 3
7)	21 — 25	12. 8
8)	15 — 24	12. 4

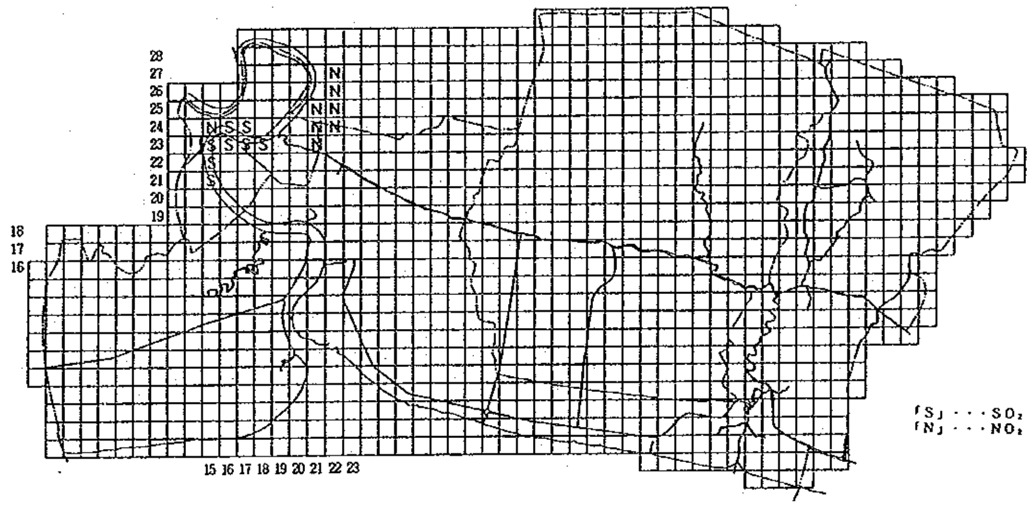


Fig. 1-24 High Concentration Points Applied for Calculation of Contribution Rate

Table 1-20 shows the contribution concentration and the contribution rate by source at the high concentration points of SO_2 and NO_2. In this table, 10 sources with higher contribution concentrations are listed. The results are summarized as follows.

The high annual average concentrations of SO_2 and NO_2 appear in the vicinity of MS3 and MS1 respectively. The contribution of the sources are in case of SO_2, factories (81.7–88.1 pct), automobiles (3.8–5.6 pct), ships (6.3–11.8 pct), ferries (0.1–8.0 pct). As for NO_2, they are factories (3.0–8.4 pct), automobiles (28.6–74.6 pct), ships (2.4–12.2 pct), and ferries (0.1–28.2 pct). In other words, the largest contributer of SO_2 and NO_2 are factories and automobiles respectively.

When the sources which are accountable for SO_2 and NO_2 are examined from the point of stack height, small groups of stationary sources which are about 10 meters high account for the largest percentage. Other than United Grain Co., Ltd. (3-75-1) in regard to SO_2, there is no single source which is accountable for more than 10 percent.

Table 1-20(1) Contribution Concentration (Yearly Average Value) at High Concentration Points of SO_2

(Rank 1 IX,IY=16,24)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	75	1	4.017	17.6
	2)	3	111	2	0.841	3.7
	3)	3	4	1	0.809	3.5
	4)	3	69	1	0.460	2.0
	5)	3	47	1	0.452	2.0
	6)	3	47	2	0.452	2.0
	7)	3	52	2	0.390	1.7
	8)	3	5	1	0.387	1.7
	9)	3	98	5	0.375	1.6
	10)	3	118	2	0.362	1.6
	Remaining stacks				4.768	20.9
	Sub total				13.313	58.2
Factory (area source)					6.014	26.3
Roadways					0.919	4.0
Vessels (sailing)					2.340	10.2
Ferryboats (anchoring)					0.026	0.1
Ferryboats (sailing)					0.154	0.7
Back ground					0.100	0.4
TOTAL					22.866	100.0

(Rank 2 IX,IY=16,23)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	75	1	2.911	12.9
	2)	3	4	1	0.872	3.9
	3)	3	111	2	0.763	3.4
	4)	3	47	2	0.700	3.1
	5)	3	47	1	0.700	3.1
	6)	3	52	2	0.607	2.7
	7)	3	69	1	0.577	2.6
	8)	3	14	2	0.428	1.9
	9)	3	14	1	0.428	1.9
	10)	3	98	5	0.418	1.9
	Remaining stacks				5.063	22.5
	Sub total				13.467	59.9
Factory (area source)					6.349	28.2
Roadways					0.969	4.3
Vessels (sailing)					1.479	6.6
Ferryboats (anchoring)					0.017	0.1
Ferryboats (sailing)					0.115	0.5
Back ground					0.100	0.4
TOTAL					22.496	100.0

(Rank 3 IX,IY=17,23)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	111	2	2.099	9.6
	2)	3	111	3	1.001	4.6
	3)	3	14	1	0.878	4.0
	4)	3	14	2	0.878	4.0
	5)	3	14	3	0.842	3.8
	6)	3	1	2	0.649	3.0
	7)	3	69	1	0.638	2.9
	8)	3	111	4	0.551	2.5
	9)	3	98	5	0.488	2.2
	10)	3	75	1	0.467	2.1
	Remaining stacks				4.661	21.3
	Sub total				13.152	60.1
Factory (area source)					6.002	27.4
Roadways					1.050	4.8
Vessels (sailing)					1.560	7.1
Ferryboats (anchoring)					0.003	0.0
Ferryboats (sailing)					0.025	0.1
Back ground					0.100	0.5
TOTAL					21.892	100.0

(Rank 4 IX,IY=15,23)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	75	1	1.354	6.5
	2)	3	47	1	1.091	5.2
	3)	3	47	2	1.091	5.2
	4)	3	5	1	0.591	2.8
	5)	3	111	2	0.410	2.0
	6)	3	59	2	0.355	1.7
	7)	3	4	1	0.330	1.6
	8)	3	98	5	0.319	1.5
	9)	3	54	1	0.293	1.4
	10)	3	52	2	0.288	1.4
	Remaining stacks				5.057	24.3
	Sub total				11.179	53.6
Factory (area source)					4.855	23.3
Roadways					0.782	3.8
Vessels (sailing)					2.250	10.8
Ferryboats (anchoring)					0.202	1.0
Ferryboats (sailing)					1.462	7.0
Back ground					0.100	0.5
TOTAL					20.840	100.0

(Rank 5 IX,IY=17,24)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	111	2	1.192	5.8
	2)	3	14	1	0.953	4.7
	3)	3	14	2	0.953	4.7
	4)	3	14	3	0.917	4.5
	5)	3	75	1	0.842	4.1
	6)	3	4	1	0.822	4.0
	7)	3	1	2	0.474	2.3
	8)	3	69	1	0.430	2.1
	9)	3	98	5	0.414	2.0
	10)	3	13	1	0.350	1.7
	Remaining stacks				4.624	22.6
	Sub total				11.971	58.6
Factory (area source)					5.584	27.3
Roadways					0.939	4.6
Vessels (sailing)					1.805	8.8
Ferryboats (anchoring)					0.005	0.0
Ferryboats (sailing)					0.037	0.2
Back ground					0.100	0.5
TOTAL					20.441	100.0

(Rank 6 IX,IY=15,22)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	75	1	0.728	3.7
	2)	3	47	1	0.696	3.5
	3)	3	47	2	0.696	3.5
	4)	3	111	2	0.498	2.5
	5)	3	51	2	0.484	2.5
	6)	3	54	1	0.442	2.2
	7)	3	51	3	0.429	2.2
	8)	3	54	3	0.378	1.9
	9)	3	54	4	0.378	1.9
	10)	3	54	2	0.378	1.9
	Remaining stacks				5.075	25.8
	Sub total				10.182	51.7
Factory (area source)					5.430	27.6
Roadways					0.902	4.6
Vessels (sailing)					2.213	11.2
Ferryboats (anchoring)					0.054	0.3
Ferryboats (sailing)					0.803	4.1
Back ground					0.100	0.5
TOTAL					19.684	100.0

(Rank 7 IX,IY=18,23)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	14	3	1.138	5.8
	2)	3	14	1	0.955	4.9
	3)	3	14	2	0.955	4.9
	4)	3	8	1	0.794	4.0
	5)	3	16	1	0.624	3.2
	6)	3	16	2	0.624	3.2
	7)	3	111	2	0.594	3.0
	8)	3	98	5	0.460	2.3
	9)	3	3	1	0.444	2.3
	10)	3	16	4	0.435	2.2
	Remaining stacks				5.108	26.0
	Sub total				12.131	61.8
Factory (area source)					5.037	25.7
Roadways					1.096	5.6
Vessels (sailing)					1.242	6.3
Ferryboats (anchoring)					0.001	0.0
Ferryboats (sailing)					0.011	0.1
Back ground					0.100	0.5
TOTAL					19.618	100.0

(Rank 8 IX,IY=15,21)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	47	1	1.025	5.4
	2)	3	47	2	1.025	5.4
	3)	3	111	2	0.421	2.2
	4)	3	75	1	0.325	1.7
	5)	3	5	1	0.320	1.7
	6)	3	95	2	0.273	1.4
	7)	3	54	1	0.243	1.3
	8)	3	98	5	0.227	1.2
	9)	3	79	1	0.212	1.1
	10)	3	14	3	0.211	1.1
	Remaining stacks				5.071	26.7
	Sub total				9.353	49.3
Factory (area source)					6.156	32.4
Roadways					0.911	4.8
Vessels (sailing)					2.236	11.8
Ferryboats (anchoring)					0.021	0.1
Ferryboats (sailing)					0.209	1.1
Back ground					0.100	0.5
TOTAL					18.986	100.0

Table 1-20(2) Contribution Concentration (Yearly Average Value) at High Concentration Points of NO_2

(Rank 1 IX,IY=22,26)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.056	0.4
	2)	3	98	3	0.033	0.2
	3)	3	98	4	0.030	0.2
	4)	3	105	2	0.024	0.2
	5)	3	98	2	0.021	0.1
	6)	3	98	1	0.021	0.1
	7)	3	105	1	0.015	0.1
	8)	1	39	1	0.007	0.0
	9)	1	70	2	0.005	0.0
	10)	1	70	1	0.004	0.0
	Remaining stacks				0.067	0.5
	Sub total				0.283	2.0
Factory (area source)					0.155	1.1
Roadways					10.646	74.6
Vessels (sailing)					0.372	2.6
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.014	0.1
Back ground					2.800	19.6
TOTAL					14.272	100.0

(Rank 2 IX,IY=22,25)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.053	0.4
	2)	3	98	3	0.032	0.2
	3)	3	98	4	0.029	0.2
	4)	3	105	2	0.025	0.2
	5)	3	98	2	0.021	0.2
	6)	3	98	1	0.020	0.1
	7)	3	105	1	0.016	0.1
	8)	1	39	1	0.009	0.1
	9)	1	70	2	0.006	0.0
	10)	1	70	1	0.005	0.0
	Remaining stacks				0.077	0.6
	Sub total				0.293	2.1
Factory (area source)					0.182	1.3
Roadways					10.177	73.7
Vessels (sailing)					0.344	2.5
Ferryboats (anchoring)					0.001	0.0
Ferryboats (sailing)					0.011	0.1
Back ground					2.800	20.3
TOTAL					13.808	100.0

(Rank 3 IX,IY=22,27)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.056	0.4
	2)	3	98	3	0.033	0.2
	3)	3	98	4	0.030	0.2
	4)	3	105	2	0.023	0.2
	5)	3	98	2	0.020	0.1
	6)	3	98	1	0.020	0.1
	7)	3	105	1	0.014	0.1
	8)	1	70	2	0.005	0.0
	9)	1	39	1	0.005	0.0
	10)	1	70	1	0.004	0.0
	Remaining stacks				0.060	0.4
	Sub total				0.270	2.0
Factory (area source)					0.133	1.0
Roadways					10.067	73.6
Vessels (sailing)					0.396	2.9
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.016	0.1
Back ground					2.800	20.5
TOTAL					13.684	100.0

(Rank 4 IX,IY=21,24)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.061	0.4
	2)	3	98	3	0.038	0.3
	3)	3	98	4	0.033	0.2
	4)	3	105	2	0.032	0.2
	5)	3	98	2	0.025	0.2
	6)	3	98	1	0.025	0.2
	7)	3	105	1	0.022	0.2
	8)	1	39	1	0.009	0.1
	9)	1	70	2	0.006	0.0
	10)	1	70	1	0.005	0.0
	Remaining stacks				0.106	0.8
	Sub total				0.362	2.7
Factory (area source)					0.278	2.0
Roadways					9.708	71.4
Vessels (sailing)					0.439	3.2
Ferryboats (anchoring)					0.001	0.0
Ferryboats (sailing)					0.012	0.1
Back ground					2.800	20.6
TOTAL					13.600	100.0

(Rank 5 IX,IY=21,23)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.052	0.4
	2)	3	105	2	0.033	0.2
	3)	3	98	3	0.032	0.2
	4)	3	98	4	0.028	0.2
	5)	3	98	2	0.023	0.2
	6)	3	98	1	0.023	0.2
	7)	3	105	1	0.023	0.2
	8)	1	39	1	0.010	0.1
	9)	1	70	2	0.006	0.0
	10)	1	70	1	0.005	0.0
	Remaining stacks				0.114	0.8
	Sub total				0.349	2.6
Factory (area source)					0.259	1.9
Roadways					9.634	71.6
Vessels (sailing)					0.397	3.0
Ferryboats (anchoring)					0.001	0.0
Ferryboats (sailing)					0.010	0.1
Back ground					2.800	20.8
TOTAL					13.450	100.0

(Rank 6 IX,IY=22,24)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.048	0.4
	2)	3	98	3	0.030	0.2
	3)	3	98	4	0.026	0.2
	4)	3	105	2	0.026	0.2
	5)	3	98	2	0.020	0.1
	6)	3	98	1	0.019	0.1
	7)	3	105	1	0.017	0.1
	8)	1	39	1	0.013	0.1
	9)	1	70	2	0.006	0.0
	10)	1	70	1	0.005	0.0
	Remaining stacks				0.091	0.7
	Sub total				0.301	2.3
Factory (area source)					0.197	1.5
Roadways					9.715	72.8
Vessels (sailing)					0.320	2.4
Ferryboats (anchoring)					0.001	0.0
Ferryboats (sailing)					0.009	0.1
Back ground					2.800	21.0
TOTAL					13.343	100.0

(Rank 7 IX,IY=21,25)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.066	0.5
	2)	3	98	3	0.040	0.3
	3)	3	98	4	0.035	0.3
	4)	3	105	2	0.030	0.2
	5)	3	98	2	0.026	0.2
	6)	3	98	1	0.025	0.2
	7)	3	105	1	0.020	0.2
	8)	1	39	1	0.007	0.1
	9)	1	70	2	0.005	0.0
	10)	1	70	1	0.004	0.0
	Remaining stacks				0.093	0.7
	Sub total				0.351	2.7
Factory (area source)					0.244	1.9
Roadways					8.892	69.3
Vessels (sailing)					0.529	4.1
Ferryboats (anchoring)					0.002	0.0
Ferryboats (sailing)					0.016	0.1
Back ground					2.800	21.8
TOTAL					12.834	100.0

(Rank 8 IX,IY=15,24)

Type of source					Conce. of contr. (ppb)	Rate of contr. (%)
	SEQ)	County	Fact No.	Sta. No.		
Factory (point)	1)	3	98	5	0.091	0.7
	2)	3	98	3	0.056	0.4
	3)	3	98	4	0.049	0.4
	4)	3	105	2	0.038	0.3
	5)	3	98	1	0.037	0.3
	6)	3	98	2	0.037	0.3
	7)	3	105	1	0.026	0.2
	8)	3	75	1	0.024	0.2
	9)	3	5	1	0.021	0.2
	10)	3	47	1	0.010	0.1
	Remaining stacks				0.162	1.3
	Sub total				0.551	4.4
Factory (area source)					0.503	4.0
Roadways					3.560	28.6
Vessels (sailing)					1.521	12.2
Ferryboats (anchoring)					0.533	4.3
Ferryboats (sailing)					2.977	23.9
Back ground					2.800	22.5
TOTAL					12.445	100.0

2. Study on Atmospheric Pollutant Concentration of Particulate Matters Estimated by Chemical Mass Balance Method

2.1 Assumption Methods of Source Contribution Rate of Particulate Matter

To clarify the correlation between an emission source and the ambient concentration of the air pollutants, source models, such as a diffusion model, have been developed based on the condition that SO_2 and NO_x emission volume from the source will be kept in the ambient in the same volume. However, as for the particulate matter, the same diffusion models cannot be applied because of the fact that of the particulate matter emitted from various sources, secondary particles are produced by chemical reaction in the ambient and modeling of the removal mechanism is not yet confirmed. It is generally understood that simulation methods are now under development. Among them, the receptor model has been developed which determines emission sources from various information of the ambient particulate matter such as concentration of the respective elements, ion concentration, particle size and forms.

In this chapter, the problem points of the source model applied for particulate matter and assumption methods of the source contribution rate by the receptor model are described.

2.1.1 Problem Points of the Source Model Applied for Particulate Matter

The source model is the method to estimate the ambient concentration and the contribution rate of each individual emission source (factory and stack) at certain points (mesh, station, etc.) based on the data on emission intensity, conditions (stack height, emission gas volume, etc.) and meteorological conditions (wind direction & velocity, atmospheric stability, etc.). For concentration calculation, the plume model, puff model and numerical model (diffusion factors are complicated) are widely used.

These diffusion models are applicable for environmental assessments which are necessary to establish environmental protection plans and location plans for new industries. These models can evaluate the above said plans and they can also evaluate the environmental impacts by the respective sources even when several sources are emitting the same types of pollutants. But as mentioned above, these models are not applicable for the assumption of ambient concentration and their contribution rate of the particulate matters due to the reasons mentioned hereafter.

(1) Ambient concentration

The instruments to measure short time (at least 1 hour) concentration of particulate matter by particle size are not yet developed. It is therefore impossible to clarify the correlation between meteorological data and particulate concentration.

(2) Emission source

It is difficult to clarify the wide range emission sources, and the generating mechanism of secondary particles quantitatively.

(a) Stationary source

The weight concentration is easy to obtain, but the data on size distribution by facilities, type of fuels, operational conditions, dust collecting facilities, etc. are not easy to obtain.

(b) Automobile

The particulate matter generated by automobiles consists of emission gases, the abrasion of tires, abrasion of pavement and particles blown up from the road. Therefore, it is very difficult to classify these particles quantitatively.

(c) Ships and aeroplanes

It is difficult to identify not only the emission factor of weight concentration but also the size distribution.

(d) Particulate generating facilities

It is difficult to obtain the data of emission volume from cement manufacturing, quarrying, steel mills, coal yards, reclamation sites, etc.

(e) Natural background source

It is difficult to clarify the volume of particulate generated by volcano eruption, sea salt, dust storm, seeds of plants, etc. quantitatively.

(f) Others

Emission factors of outdoor burning of wastes, straw, etc. are unkonwn.

(3) Prediction model

It is necessary to develop a new model which includes gravity fallout of the particulate, generation of secondary particles, removal mechanism of particulate, etc.

2.1.2 Receptor Model

The receptor model is the method to identify the sources and their contribution rate based on the data on chemical composition, particle size, concentration variation, particle form, etc. which are obtained at a certain point and a certain period. This method has been recently highlighted due to the development of microanalysis techniques. Many studies on the receptor model have been carried out.

This method has the advantage of being able to identify the source and contribution rate without considering meteorological and geographical conditions, and also of being able to identify the new sources and sources for which data is difficult to obtain. Further, it is applicable for evaluation of emission sources which should be realized in case of high concentration, by using data measured. However, the receptor model is not effective for identification of each individual source when some emission sources emitting similar chemical substraits are existing as this model can be applied to one source type only, while the source model can be applied for evaluation of the ambient concentration that each individual emission source affects. The evaluation by receptor model is only limited to the area of monitoring stations and it is also impossible to predict the future conditions.

The receptor model can be classified to the morphological observation, physical analysis and chemical analysis, as shown in Fig. 2-1.

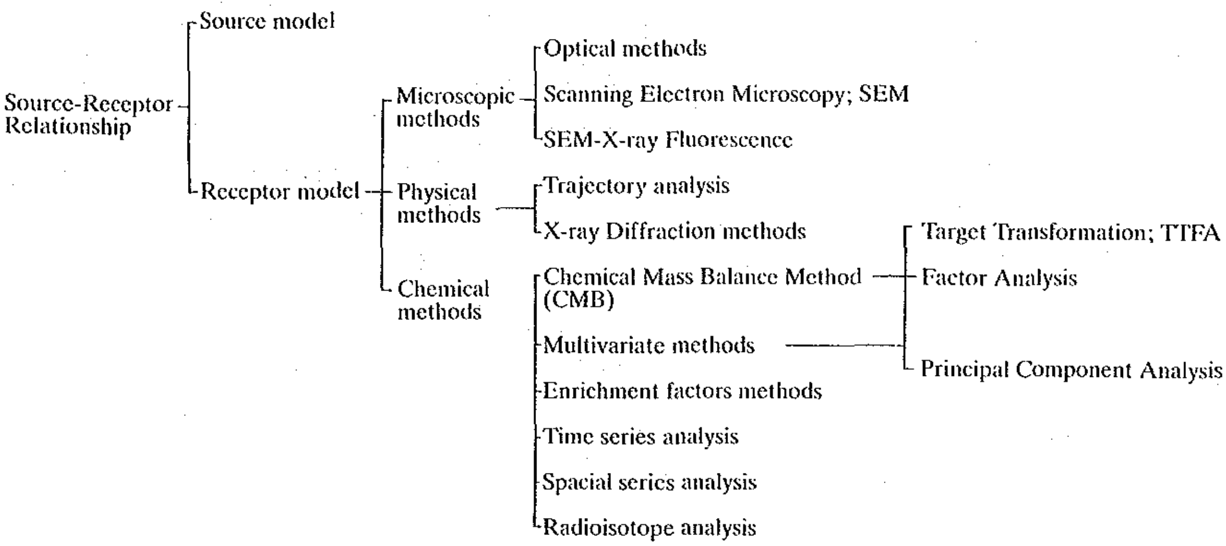


Fig. 2-1 Contribution Rate Assumption Methods of Particulate Matter

(1) Morphological observation method

The morphological observation method assumes the source from the size of particulate, color, form, surface characteristics, and optical nature. This method is most effective to identify the source from trees' tissue and pollen. But for the analysis by this method, a large number of particles must be observed, and it takes time and cost. It has also the disadvantage that its sensitivity is not sufficient to identify the organic particles and non-crystalline particles.

(2) Physical analysis

① Trajectory line analysis

This method is to identify the source by following up the trajectory line from the monitoring point to windward in order, based on the data of wind direction and velocity.

This method is often used to identify the source when the concentration of pollutants has reached a high level. This method is rather simple but the contribution of a certain source cannot be evaluated quantitatively.

② X-ray analysis

This method is to identify the crystalline particle quantitatively, such as mineral, cement dust, calcium carbonate, etc. But it is not suitable for non-crystalline particle and fine particles.

(3) Chemical analysis

① Radioisotope method

This method is based on the principle that $^{14}C/^{12}C$ of carbon compounds are measured and it is used for the apportionment of carbon from crude oil and other carbon. The half life of ^{14}C is 5,730 years and so the crude oil is identified as not containing ^{14}C because it has been stored and accumulated for several hundred million years.[1)]

② Concentration factor method

This method is to measure the concentration factor of the element (i) contained in the particles and to evaluate the impact by the emission sources, as shown in the following equation. If the data for chemical components at the emission sources are available, the quantitative analysis is also possible.

$$EFi = \frac{(Ci/Cs)\ \text{aerosol}}{(Ci/Cs)\ \text{reference}}$$

where; the concentration ratio is between trace element (i) and standard element (s).

③ Time series analysis and space distribution analysis

These methods are to assume the emission source from the time series correlation of particulate weight and chemical components, and from space distribution of chemical components and those at the emission sources. The method itself is rather simple, but it is not suitable to identify the particular sources and quantitative assumption.

④ Chemical Mass Balance method

This method was proposed by Miller et al.[19)] and it is to estimate the emission sources quantitatively by statistical processing of chemical components of the particulates at the monitoring point and emission source.

⑤ Multivariate analysis

Multivariate analysis methods are main components analysis, factor analysis, regression analysis, cluster analysis, etc. These methods are all to obtain the information related to the emission sources from the variation between many samples collected for chemical components of the particulates. For these methods, advance information on the type of sources and chemical components are not required. These methods have been further improved into the TTFA method (Target Transformation Factor Analysis)[20)] which is to estimate the emission sources contribution rate quantitatively. This TTFA method has been recently highlighted among researchers.

2.2 Estimation of Contribution Rates of Emission Source Types on Particulate Matters by CMB Method

In this chapter, using chemical components data measured during each short term field survey, we estimate the contribution rates of each emission source type on particulate matters.

2.2.1 Outline of the CMB (Chemical Mass Balance) Method

The CMB method is the technique that estimates the contribution rate of each emission source using two types of data: the measurement data of the chemical components on particulate matters at one receptor site during a certain period of time, and the data of the chemical composition of each emission source type. Recently, this method has received attention with the progress of analysis techniques. But, this method cannot distinguish the contribution rates of the similar emission source types, and the estimations are confined to the area of measurement stations and the prediction for future is impossible.

(1) Estimation method for contribution rates of source types on particulate matters by the CMB method

The following equation explains the basis of the CMB method.

$$\left[\begin{array}{l}\text{The chemical com-}\\ \text{ponents concentra-}\\ \text{tions at one receptor}\\ \text{site}\end{array}\right] = \left[\begin{array}{l}\text{The concentrations}\\ \text{contributed by each}\\ \text{emission source type}\end{array}\right] \times \left[\begin{array}{l}\text{The rates of each}\\ \text{chemical component}\\ \text{of the emission}\\ \text{source types on par-}\\ \text{ticulate matter}\end{array}\right] \quad \ldots\ldots \ (2\text{-}1)$$

An example showing the basis of the CMB method is given as follows: In this case, it is assumed that the emission sources are two types, and Al and Ca are emitted from only two source types: Soil and Factories.

The chemical components composition of the emission source on particulate matters is supposed as follows:

Emission sources / Chemical components	Soil	Factories
Al	10%	5%
Ca	1%	3%

The chemical concentration at a receptor site is supposed as follows:

Chemical concentration	10 $\mu g/m^3$
Al	0.55 $\mu g/m^3$
Ca	0.08 $\mu g/m^3$

So the following matrices are defined.

$$C = \begin{bmatrix} C_1 \\ C_2 \\ \vdots \\ \vdots \\ C_i \end{bmatrix} \quad F = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1j} \\ f_{21} & f_{22} & \cdots & f_{2j} \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ f_{i1} & f_{i2} & \cdots & f_{ij} \end{bmatrix} \quad S = \begin{bmatrix} S_1 \\ \vdots \\ S_j \end{bmatrix}$$

C_i: The concentration of component (i) in suspended particulate matter at one receptor site

f_{ij}: The proportion of component (i) concentration emitted from the source (j)

S_j: The concentration of dust emitted from source (j)

j=1: Soil
j=2: Factories

In this case, the emission source types related to Al and Ca are restricted to Soil and Factories. Then, concerning Al, the concentration on particulate matter at one receptor site is the sum of two values; the product of Soil contribution rates and Al concentration rates in Soil, and the producdts of Factories contribution rates and Al concentration rates in Factories. The variables, S_1 and S_2 satisfy the following equations (2-2).

$$\left.\begin{array}{l} \text{about Al} \\ \quad 0.10\times S_1+0.05\times S_2 = 0.55 \\ \text{about Ca} \\ \quad 0.01\times S_1+0.03\times S_2 = 0.08 \end{array}\right\} \quad \cdots\cdots \quad (2\text{-}2)$$

The following determinant (2-3) satisfies this simultaneous equation.

$$\begin{bmatrix} 0.55\ \mu g/m^3 \\ \\ 0.08\ \mu g/m^3 \end{bmatrix} = \begin{bmatrix} 0.10 & 0.05 \\ \\ 0.01 & 0.03 \end{bmatrix} \begin{bmatrix} S_1 & \mu g/m^3 \\ \\ S_2 & \mu g/m^3 \end{bmatrix} \quad \cdots\cdots \quad (2\text{-}3)$$

That is

$$C=FS \quad \cdots\cdots \quad (2\text{-}4)$$

The results are as follows:

$S_1=5.0\ \mu g/m^3$

$S_2=1.0\ \mu g/m^3$

Then the contribution (rates) of Soil is 5.0 $\mu g/m^3$ (50%) and that of Factories is 1.0 $\mu g/m^3$ (10%).

In general, the chemical composition is determined for each emission source type (Soil, Sea salt particle, Fuel combustion, Refuse incineration, Automobile, etc.), and the contribution rates of each emission source type is estimated with the following equation (2-5):

$$C_i = \sum_{j=1}^{m} F_{ij} \cdot \alpha_{ij} \cdot S_j \quad \cdots\cdots \quad (2\text{-}5)$$

where;

α_{ij}: Conversion rate of component (i) from the source (j)

In general, the value of α_{ij} is assumed to be 1, then Equation (2-5) is written as follows:

$$C_i = \sum_{j=1}^{m} F_{ij} \cdot S_j \qquad (2\text{-}6)$$

The CMB method is the technique by which S_j is estimated using the known values, F_{ij} and C_i.

When we measure the component concentration, C_i ($i=1, 2, \ldots n$), the following simultaneous equation can be derived from Equation (2-6).

$$\left.\begin{array}{l} C_1=F_{11}\cdot S_1+F_{12}\cdot S_2+\ldots+F_{1m}\cdot S_m \\ C_2=F_{21}\cdot S_1+F_{22}\cdot S_2+\ldots+F_{2m}\cdot S_m \\ C_n=F_{n1}\cdot S_1+F_{n2}\cdot S_2+\ldots+F_{nm}\cdot S_m \end{array}\right\} \quad \cdots\cdots \quad (2\text{-}7)$$

where:

m: Number of emission sources

n: Number of receptor sites

Now we express Equation (2-7) in matrix, then

$$C=F\cdot S \quad \cdots\cdots \quad (2\text{-}8)$$

is obtained.

where $n \geqq m$ .... (2-9)

The methods of solution on Equation (2-6) have been variously proposed. Some of them are as follows:

(1) Simultaneous equation method
(2) Least-squares method
(3) Weighted least-squares method
(4) Effective variance method
(5) Ridge regression method

1) CMB method using simultaneous equation

If the number of C_i and F_{ij} is equal to that of emission sources in Equation (2-6), we can get the unique solution. So in this method we select market elements whose number equals to the number of emission sources and obtain the simultaneous equation. (Equation 2-6) Solving this equation, we estimate the contributions on the concentrations at receptor sites from emission sources.

When n equals to m, matrix F becomes a square matrix. Multiplying both sides of Equation (2-8) by F^{-1} (inverse matrix), we can get S.

$$S=F^{-1}\cdot C \quad \cdots\cdots\cdots\cdots \quad (2\text{-}10)$$

2) CMB method using least-squares method

If n (number of receptors) is greater than m (number of emission sources), Equation (2-6) generally has solutions S. In this method, we select $\hat{S}$ (the presumed value of S) which makes the residual of C and $\hat{C}$ ($\hat{C}=F\cdot\hat{S}$) minimum. When we define the residual vector $E=\hat{C}-C$, sum of squares about residual ε^2 is expressed by following equation:

$$\begin{aligned}\varepsilon^2 &= E^t\cdot E=(\hat{C}-C)^t\cdot(\hat{C}-C)\\ &=(F\cdot\hat{S}-C)^t\cdot(F\cdot\hat{S}-C) \quad \cdots\cdots\cdots\cdots \quad (2\text{-}11)\end{aligned}$$

where

$(\hat{C}-C)^t$ is the transposed matrix of $(\hat{C}-C)$

The condition which makes ε^2 minimum is as follows:

$$\left.\begin{aligned}&\frac{\partial \epsilon^2}{\partial S}=0\\ &\frac{\partial \epsilon^2}{\partial S}=2F_t\cdot(F\cdot\hat{S}-C)=0\end{aligned}\right\} \quad \cdots\cdots\cdots\cdots \quad (2\text{-}12)$$

We transform Equation (2-12), then following equation is obtained.

$$\hat{S}=(F^t \cdot F)^{-1} \cdot F^t \cdot C \quad \text{(2-13)}$$

3) CMB method using weighted least-squares method

Generally in the least-squares method, the whole data are treated equally. But it is usual for the accuracy of the data to differ. So we weigh the more accurate data with more weight and weigh the less accurate data with less weight. Such technique is called the weighted least-squares method. In this case, we adopted the inverse of the standard error (the standard deviation of accidental error) as the weight.

When we perform measurements of concentration C_i in k times, the vlaue of C_i can be obtained as the following equation:

$$C_i = \frac{1}{k}\sum_{\alpha=1}^{k} C_{i\alpha} \quad \text{(2-14)}$$

σ_i (the standard deviation of C_i) and S_i (standard error) are defined as follows:

$$\sigma_i = \sqrt{\sum_{\alpha=1}^{k}(C_{i\alpha}-C_i)^2/(k-1)} \quad \text{(2-15)}$$

$$S_i = \frac{\sigma_i}{\sqrt{k}} = \sqrt{\sum_{\alpha=1}^{k}(C_{i\alpha}-C_i)^2/k(k-1)} \quad \text{(2-16)}$$

Thus, the basic Equation (2-6) is modified.

$$\frac{C_i}{S_i} = \frac{1}{S_i}\sum_{j=1}^{m} F_{ij} \cdot S_j = \sum_{j=1}^{m} \frac{F_{ij}}{S_i} \cdot S_j \quad \text{(2-17)}$$

Here, we define the weight matrix W as follows:

$$\left.\begin{aligned} W &= \{W_{ij}^{2}\} \\ W_{ij} &= \begin{Bmatrix} \frac{1}{S_i} & (i=j) \\ 0 & (i \neq j) \end{Bmatrix} \end{aligned}\right\} \quad \text{(2-18)}$$

Using Equation (2-18), Equation (2-17) is expressed by matrix.

$$W^{1/2} \cdot C = W^{1/2} \cdot F \cdot S \quad \text{(2-19)}$$

Then we can obtain the estimated value $\hat{S}$

$$\left.\begin{aligned} \hat{S} &= \{(W^{1/2} \cdot F)^t \cdot (W^{1/2} \cdot F)\}^{-1} \cdot (W^{1/2} \cdot F)^t \cdot W^{1/2} \cdot C \\ &= (F^t \cdot W \cdot F)^{-1} \cdot F^t \cdot W \cdot C \end{aligned}\right\} \quad \text{(2-20)}$$

(2) The emission source types and the composition of the emission sources

1) The emission source types

To estimate the contribution rates of the emission source types on particulate matters by the CMB method, it is necessary to determine the particular chemical components (the marker elements) of each emission source type. And it is difficult to estimate the contribution rate of the emission source type without marker elements.

At present, the marker elements are considered for these emission source types: Soil, Sea salt, Gasoline automobiles, Fuel oil combustion, Iron and steel industry, Refuse incineration, Cement (includes Road dust), etc.

2) The composition of the emission sources

To estimate the contribution rates in the particulate matters by the CMB method accurately, it is very important to take the composition data of each emission source type. But the composition data are variable depending on the conditions (operation and facilities), and so it is very difficult and takes a lot of money and time to measure the representative accurate data of the emission sources. And in the case of making use of the data according to the literature, the results of the estimation are not reliable because of the gap between this data and the actual emission sources.

3) The weight coefficient

To estimate the contribution rates on the particulate matter by the weighted least-squares method, it is required to calculate the error variance of each chemical concentration. In recent studies, someone used unique error variances (Watson21)), but Scheff22) decides them using the results of repeated analyses on samples. And Kowalczyk23) considered the variance of analysis error by instrument neutron activation analysis and the value of the filter blank.

2.2.2 The Estimation of the Contribution Rates of the Emission Source Types on Particulate Matters by the CMB Method

(1) Method of the estimation

According to the former discussion about the stability of the estimation results by the Industrial Pollution Control Association of Japan (IPCAJ)24), the weighted least-squares method is adapted for the estimation.

(2) Emission source types

The contributions of the emission source types are estimated by using 8 emission source types. These are:

①Sea salt
② Soil
③ Diesel automobile

④ Gasolien automobile
⑤ Iron and steel industry
⑥ Fuel oil combustion
⑦ Refuse incineration
⑧ Road dust

(3) The composition of the emission sources

The chemical components of each emission source type are determined as follows:

① Seal salt	Na, Br
② Soil	Al, Ca, Sc, Fe, Ti
③ Diesel automobile	Elemental carbon, Organic carbon
④ Gasoline automobile	Pb, Br
⑤ Iron and steel industry	Mn, Fe, Zn, Cr
⑥ Fuel oil combustion	V, Ni
⑦ Refuse incineration	K, Zn, Sb
⑧ Road dust	Pb, Ca, Fe, Sc

Table 2-1 shows the chemical compositions of the emission source types (emission source matrices). Now, the matrices of Soil and Road dust are determined by the actual samples collected in the Samut Prakarn industrial district, and other matrices are selected from the literature.

The grounds for setting the emission source matrices are explained as follows:

① Sea salt particle

The chemical composition of the emission source is the same as the composition of the sea water itself, and the matrix data by Mizobata[25)] were cited.

② Soil and Road dust

The actual sample data of the soil and the road dust were used. The sampling points are illustrated in Fig. 2-2.

Table 2-1 The Matrix on the Component Concentrations in Emission Sources

(unit;ppm)

	Sea salt	Soil	Diesel automobile	Gasoline automobile	Iron and steel Ind.	Fuel oil combustion	Refuse incineration	Road dust
Al	0.3	55500	240	1300	18000	14250	9770	50000
Br	1900	17.5	0	20000	140	60	6420	150
Ca	12000	1750	3260	0	47000	14500	13600	26000
Cr	0.001	27.5	46	21	4230	2760	570	33
Fe	0.29	12000	30700	4900	301000	28300	5900	18000
K	11000	31500	120	2000	11500	1300	100000	21000
Mn	0.058	365	77	51	27700	500	540	610
Na	304200	6500	120	200	7150	37800	88300	7200
Ni	0.014	30	0	38	1700	21000	135	25
Pb	0.087	70	490	120000	10500	900	53400	130
Sb	0.014	1.575	0.48	1.9	90	10	1120	3.4
Sc	0.001	4.45	0	0.12	2.9	0.33	0.74	4.5
Se	0.12	9.2	3.0	0	51	67	33	6.1
Ti	0.029	2700	0	0	1000	430	1380	2300
V	0.058	35.5	2.9	2.1	365	37700	27	46
Zn	0.029	17.5	1160	1400	26000	1700	79400	130
Cele	0	3250	620000	301000	33000	371000	94000	16900
Corg	0	1000	100000	263000	33000	24000	15000	600

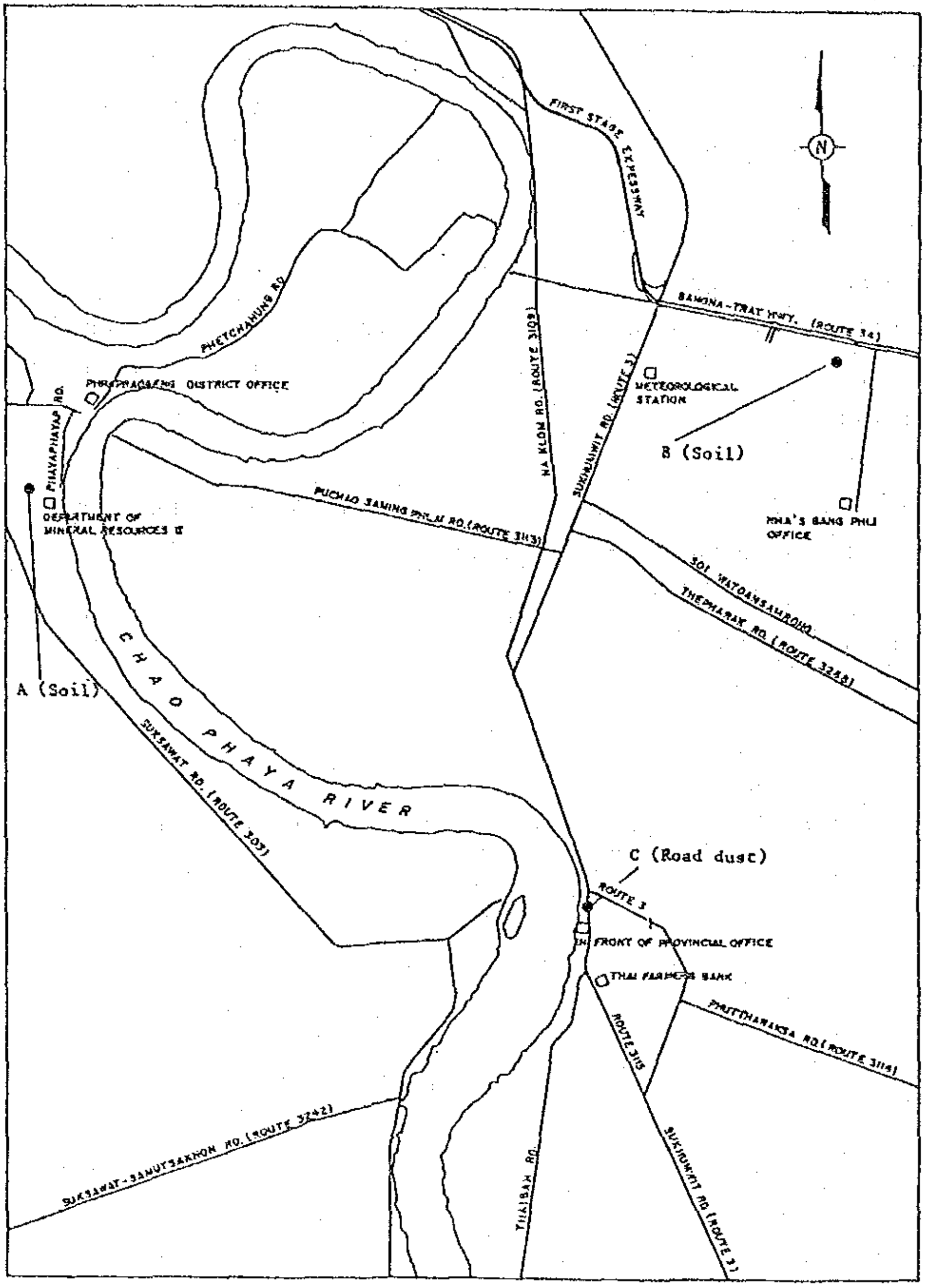


Fig. 2-2 Location of the Sampling Points for Soil and Road Dust

Soil: used the average data of these sampled at points A and B

Road dust: used the road dust data sampled at point C

③ Diesel automobile

The average of the data of Fukuzaki[26)], Hayashi[27)] and Koyama[28)] was used.

④ Gasoline automobile

The data of the leased gasoline automobile by Mizobata[25)] was used. Moreover, the data of the carbon by Naito[29)] was added.

⑤ Iron and steel industry

The average of the data of Mizobata[25)], Catz[30)], and Scheff[31)] was used. And the data of the carbon by Hayashi[27)] was cited.

⑥ Fuel oil combustion

The average of the data of Mizobata[25)], Hayashi[27)], Scheff[31)], Friedlander[32)] and Kowalczyk[33)] was used.

⑦ Refuse incineration

The average of the data of Mizobata[25)] and Scheff[31)] was used.

(4) The chemical concentrations on particulate matters (The chemical concentrations at the receptor sites)

The chemical components data used for the estimation of the contribution rates of the emission source types on particulate matters were measured by the low-volume sampler at each monitoring station during each short time field survey. The method of the analysis and the data of these chemical components (33 elements, 7 ions, elemental carbon and organic carbon) were as shown in PART II. Then 18 chemical components shown in Table 2-2 are selected as the index elements. In addition, the contribution rates are not estimated using the data of the Andersen sampler, because the carbon components data are lacking.

Table 2-2 Monitoring Data of Chemical Component by Low Volume Sampler for the CMB Method (unit: ng/m^3)

Chemical Component	1st Survey					2nd Survey					3rd Survey				
	MS 1	MS 2	MS 3	MS 4	MS 5	MS 1	MS 2	MS 3	MS 4	MS 5	MS 1	MS 2	MS 3	MS 4	MS 5
Al	1300	810	1100	1400	2200	760	310	490	650	570	770	410	410	820	740
Br	42	17	31	37	18	14	9	19	11	12	26	4.5	9.5	15	7.2
Ca	2100	1200	2600	1600	2100	730	<800	2000	1600	<500	1700	800	1300	1500	1300
Cr	6.5	7.3	31	5.1	3.3	3.7	10.0	10.0	2.9	0.77	7.9	7.9	7.3	4.5	5.0
Fe	1700	1300	4700	1700	1100	700	420	2000	400	260	1200	840	1700	940	450
K	1300	1100	1700	1200	2000	640	350	1300	750	540	<800	1400	1100	<800	<900
Mn	60	58	360	75	41	50	11	200	24	15	71	23	72	34	21
Na	1100	1700	1400	1500	1100	1400	2800	2100	1900	1800	780	1000	840	1100	790
Ni	19	< 20	47	< 10	< 8	< 7	19	55	6	< 6	< 10	22	18	< 10	15
Pb	450	1590	780	290	30	50	20	380	50	< 10	220	1100	230	140	40
Sb	29	64	17	17	5.4	5.1	1.4	6.5	1.7	0.47	5.6	32	10	4.1	3.1
Sc	0.20	0.13	0.19	0.20	0.23	0.11	0.054	0.078	0.076	0.071	0.15	0.11	0.10	0.14	0.15
Se	<0.9	<1.0	<2.0	<0.8	0.96	1.1	51	1.5	0.5	0.95	1.7	<1.0	<0.8	<0.7	<0.6
Ti	67	86	130	140	150	97	98	57	<100	82	62	< 40	66	59	51
V	12	16	35	7.4	5.0	6.4	26	63	4.5	2.1	8.7	13	22	6.3	3.4
Zn	720	900	3700	760	140	250	82	2900	100	18	960	370	1100	370	160
Cele	15300	13500	16400	16200	9500	7500	7500	11500	11500	6200	10600	5500	8100	9700	4000
Corg	8700	5800	10800	9400	5700	4300	4000	5300	5800	4100	2700	2000	3200	4000	2000

(5) The weighted coefficient

The weighted coefficient is the reciprocal of the measurement error. The chemical components shown in Table 2-2 were measured by the neutron activation analysis except for Pb and elemental carbon and organic carbon; Pb was measured by the X-ray fluorescence and these carbons were measured by the thermal analysis. So, now the precision (the rates of variance on four measurement data) of the chemical components by IPCAJ[24)] are mainly adapted, because the method of analysis is similar to this preceding report. The precisions of the components (K, Ni, Se) of which measurement errors were not evaluated because of the lack of effective data, and of the components (elemental carbon & organic carbon) of which measurement errors were not reported were cited from the reports of Nagatsuka[34)] and Hayashi[35)], respectively. These precisions are shown in Table 2-3.

In addition, the concentrations of the components under the detection limit shown in Table 2-2 were assumed to be 1/2 times of detection limits and the precisions are assumed 10 times (1000%) values.

Table 2-3 Precision of Chemical Component
(unit: %)

Component	IPCAJ	Naga-tsuka et al.	Hayashi	Adopted
Al	5.8	15.7	—	5.8
Br	27.0	33.0	—	27.0
Ca	16.6	8.4	—	16.6
Cr	10.1	3.9	—	10.1
Fe	11.4	15.0	—	11.4
K	—	5.6	—	5.6
Mn	10.1	7.8	—	10.1
Na	10.1	13.8	—	10.1
Ni	—	—	—	10.0
Pb	11.0	—	—	11.0
Sb	5.6	22.6	—	5.6
Sc	9.6	22.9	—	9.6
Se	—	—	—	10.0
Ti	39.4	—	—	39.4
V	5.8	—	—	5.8
Zn	7.4	10.7	—	7.4
Cele	1.7	—	1.7	1.7
Corg	4.8	—	4.8	4.8

2.2.3 The Results of the Estimation by the CMB Method

(1) The results of estimation by the CMB method with 8 emission source types

The contribution rates of the emission source tyes on particulate matters were estimated by the weighted least-squares method at every measurement station (MS1–MS5) during each short term field survey (1st–3rd). The results are shown in Table 2-4.

Table 2-4 The Results of the Estimation by CMB Method (8 Emission Sources)

[First survey] (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	-0.2	2.6	-0.7	1.7	3.9
Soil	-65.1	-40.7	-30.8	-59.7	57.1
Diesel automobile	35.0	34.8	27.4	32.8	27.1
Gasoline automobile	-0.3	-3.4	-2.2	-2.0	-1.3
Iron and steel Ind.	0.0	0.7	8.9	-0.5	0.2
Fuel oil combustion	0.4	0.6	1.0	0.2	0.1
Refuse incineration	15.9	17.2	16.7	13.0	3.7
Road dust	112.5	68.5	53.1	102.7	29.6
TOTAL	98.2	80.4	73.4	88.2	120.3

[Second survey] (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	9.9	20.6	9.2	15.3	22.6
Soil	-15.7	8.3	53.7	87.7	36.8
Diesel automobile	34.3	31.1	36.3	49.6	35.2
Gasoline automobile	-3.2	-0.9	-0.6	-0.5	-0.3
Iron and steel Ind.	0.8	0.6	3.2	1.0	-0.2
Fuel oil combustion	0.4	1.9	3.3	0.3	0.2
Refuse incineration	9.6	2.6	12.5	3.1	0.7
Road dust	60.4	5.9	-43.0	-64.5	3.6
TOTAL	96.6	70.1	74.6	92.0	98.5

[Third survey] (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	1.4	4.2	-0.2	4.4	6.3
Soil	-109.0	57.8	-22.7	-67.5	-1.0
Diesel automobile	38.4	29.2	32.5	33.7	22.9
Gasoline automobile	-0.3	-4.6	-5.2	-0.9	-2.1
Iron and steel Ind.	2.4	2.7	2.4	0.8	1.8
Fuel oil combustion	0.4	1.1	1.4	0.3	0.3
Refuse incineration	11.8	17.5	21.9	7.8	7.2
Road dust	154.6	-40.8	42.0	108.3	48.4
TOTAL	99.8	67.1	72.2	86.9	83.8

From the results, the abnormalities such as negative contribution rates on Soil, the over 100-percent contribution rates on Road dust and so on are suggested. Furthermore, the correlation coefficients among each emission source type are calculated with the chemical composition data (Table 2-1), and the results are shown in Table 2-5.

The result that the correlation coefficient between Road dust and Soil is 0.866 indicates the both emission source types are very similar. In the case of the CMB method, the similarity of some emission source types brings about the accidental error called property of multiple collinearity, and so the estimation is not possible because of instability. In this case, it appears to be in this condition.

Table 2-5 The Correlation Matrix among Emission Sources

Emission source	Sea salt	Soil	Diesel	Gaso-line	Iron Steel	Fuel oil	Refuse	Road dust
Sea salt	1.000	0.014	-0.077	-0.115	-0.079	0.015	0.427	0.007
Soil	0.014	1.000	-0.064	-0.136	0.113	-0.041	0.183	0.866
Diesel automobile	-0.077	-0.064	1.000	0.794	0.065	0.983	0.432	0.153
Gasoline automobile	-0.115	-0.136	0.794	1.000	0.007	0.710	0.345	-0.010
Iron and Steel Ind.	-0.079	0.113	0.065	0.007	1.000	0.067	-0.068	0.267
Fuel oil combustion	0.015	-0.041	0.983	0.710	0.067	1.000	0.452	0.189
Refuse incineration	0.427	0.183	0.432	0.345	-0.068	0.452	1.000	0.180
Road dust	0.007	0.866	0.153	-0.010	0.267	0.189	0.180	1.000

(2) The results of the estimation by the CMB method with 7 emission source types

The results calculated by the CMB method with 8 emission source types were unstable due to the similarity of the component compositions between Soil and Road dust (the correlation coefficient is 0.866). So in the next place, the contribution rates are estimated with 7 emission source types; the average value of Soil is adapted as Soil+Road dust.

The results shown in Table 2-6 indicates that the contribution rates of Gasoline automobile are negative at many stations, and the contribution rates of Refuse incineration are abnormally high. And the total contribution rate is over 100 percent at MS5 (1st survey).

Table 2-6 The Results of the Estimation by the CMB Method (7 Sources)

【First survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	1.4	4.1	0.0	3.0	4.1
Soil + Road dust	32.2	20.5	16.1	27.8	82.3
Diesel automobile	37.3	36.2	28.4	35.0	27.8
Gasoline automobile	1.3	-2.0	-1.4	-0.7	-1.3
Iron and steel Ind.	1.0	1.4	9.3	0.2	0.3
Fuel oil combustion	0.5	0.6	1.0	0.2	0.2
Refuse incineration	12.1	13.6	15.1	10.0	3.6
TOTAL	85.7	74.3	68.5	75.5	116.9

【Second survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	10.3	20.5	9.0	15.2	22.7
Soil + Road dust	35.0	13.3	15.4	32.2	39.9
Diesel automobile	35.7	31.2	35.5	47.8	35.3
Gasoline automobile	-2.9	-0.9	-0.9	-0.6	-0.3
Iron and steel Ind.	1.2	0.7	2.9	0.5	-0.2
Fuel oil combustion	0.4	1.9	3.3	0.3	0.2
Refuse incineration	8.9	2.6	12.9	3.3	0.7
TOTAL	88.6	69.3	78.1	98.7	98.2

【Third survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	3.1	3.8	0.3	5.0	6.7
Soil + Road dust	17.1	21.4	14.9	18.0	37.7
Diesel automobile	41.5	28.4	33.3	36.0	24.0
Gasoline automobile	1.4	-5.0	-4.6	-0.1	-1.9
Iron and steel Ind.	3.8	2.3	2.7	1.7	2.3
Fuel oil combustion	0.4	1.1	1.4	0.3	0.3
Refuse incineration	7.6	18.0	20.7	6.0	6.8
TOTAL	74.9	70.0	68.8	67.0	75.9

(3) The results of the estimation by CMB method with 7 emission source types (The emission source matrices of Gasoline automobile, Diesel automobile and Refuse incineration are modified)

The results of the estimation with 7 emission source types and abnormalities such as negative contribution rates and abnormally high contribution rates. This explains why the emission source matrices of Gasoline automobile, Diesel automobile and Refuse incineration are unsuitable, so the reexamination is made as follows:

① Gasoline automobile

Ca concentration was 0 ppm in the adapted emission source matrix of Gasoline automobile. But it appears that the emission source of Gasoline automobile contains Ca. So, Ca concentration in the emission source matrix of Gasoline automobile is modified to 1800 ppm according to the data by Fukuzaki[26].

② Diesel automobile

The average values of the data by Fukuzaki, Hayashi[27] and Koyama were the adapted emission source matrix of Diesel automobile. Table 2-7 shows the comparison of Fe concentrations by each literature.

As this table shows, the variance of these data is large and the data by Fukuzaki is higher than others. So the value of Fe concentration is set at 360 ppm according to Koyama.

Table 2-7 The Comparison of Fe Concentrations Included in the Emission Source (*Diesel Automobile*)

	Fukuzaki	Hayashi	Koyama
Fe	61000 ppm	0 ppm	360 ppm

③ Refuse incineration

The average values of the data by Mizobata and Scheff were adapted to the emission source matrix of Refuse incineration. But there were large differences in both components composition data. In this case, the data by Mizobata is adapted for convenience. Table 2-8 shows the emission source matrices modified as before. So thecontribution rates estimated with this modified emission source matrices are shown in Table 2-9.

Table 2-8 The Matrix on the Component Concentrations in Emission Sources (Gasoline Automobile, Diesel Automobile and Refuse Incineration are Modified)

(unit;ppm)

	Sea salt	Soil + Road dust	Diesel automobile	Gasoline automobile	Iron and steel ind.	Fuel oil combustion	Refuse incineration
Al	0.3	55500	240	1300	18000	14250	4200
Br	1900	17.5	0	20000	140	60	830
Ca	12000	1750	3260	1800	47000	14500	11000
Cr	0.001	27.5	46	21	4230	2760	850
Fe	0.29	12000	360	4900	301000	28300	6200
K	11000	31500	120	2000	11500	1300	200000
Mn	0.058	365	77	51	27700	500	330
Na	304200	6500	120	200	7150	37600	120000
Ni	0.014	30	0	38	1700	21000	135
Pb	0.087	70	490	120000	10500	900	17000
Sb	0.014	1.575	0.48	1.9	90	10	610
Sc	0.001	4.45	0	0.12	2.9	0.33	0.46
Se	0.12	9.2	3.0	0	51	67	33
Ti	0.029	2700	0	0	1000	430	900
V	0.058	35.5	2.9	2.1	365	37700	27
Zn	0.029	17.5	1160	1400	26000	1700	26000
Cele	0	3250	620000	301000	33000	371000	94000
Corg	0	1000	100000	263000	33000	24000	15000

Table 2-9 The Results of the Estimation by the CMB Method
(7 Sources; Gasoline Automobile, Diesel Automobile and Refuse Incineration are Modified)

【First survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	2.5	6.0	0.9	4.7	1.9
Soil + Road dust	33.1	23.7	17.1	34.4	66.3
Diesel automobile	34.3	36.0	27.9	37.3	24.1
Gasoline automobile	5.2	1.9	3.2	3.2	-0.7
Iron and steel ind.	1.6	2.2	11.0	0.9	-0.3
Fuel oil combustion	0.4	0.6	1.0	0.2	0.1
Refuse incineration	5.1	5.8	8.8	4.3	7.3
TOTAL	82.2	76.2	69.8	85.1	98.6

【Second survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	9.2	14.2	5.2	12.6	20.0
Soil + Road dust	30.3	10.2	12.0	28.8	38.8
Diesel automobile	32.3	29.5	27.3	47.7	33.7
Gasoline automobile	0.1	-0.3	2.4	0.0	-0.2
Iron and steel ind.	1.6	1.0	2.2	0.8	-0.3
Fuel oil combustion	0.4	1.8	2.7	0.3	0.2
Refuse incineration	5.8	3.4	10.7	5.6	1.7
TOTAL	79.7	59.9	62.6	95.9	93.9

【Third survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	4.5	-0.5	0.5	6.4	6.1
Soil + Road dust	23.5	21.3	14.9	23.5	30.9
Diesel automobile	38.1	26.1	28.5	37.6	23.3
Gasoline automobile	3.8	0.1	1.5	2.3	0.2
Iron and steel ind.	4.4	2.4	2.9	2.4	3.0
Fuel oil combustion	0.4	1.1	1.3	0.3	0.3
Refuse incineration	1.4	24.8	13.0	2.0	6.0
TOTAL	76.0	75.4	62.6	74.6	69.8

At many monitoring stations, the contribution rates of Gasoline automobile, Iron and steel industry and Sea salt are negative, and the contribution rate of Refuse incineration is abnormally large as the former estimation (2).

(4) The results of the estimation by the CMB method with 6 emission source types

There is no large refuse incineration factory in Sumut Prakarn industrial district. In spite of this condition, the former results ((1)~(3)) were estimated with 7 or 8 emission source types including Refuse incineration. In Refuse incineration, a large amount of Pb, K and Na are contained and these components are also in Gasoline automobile, Iron and steel industries and Sea salt. So, it seems Refuse incineration brought about the confusing results. Then, in the next place, the contribution rates of emission source types are examined with 6 source types excluded Refuse incineration. Table 2-10 shows the results of this estimation.

These results seem to be proper except for the over 100 percent contribution rates at MS5 (first survey) and at MS4 (second survey).

Table 2-10 The Results of the Estimation by the CMB Method
(6 Sources; Refuse Incineration are Excluded)

【First survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	4.6	9.0	4.6	6.5	4.5
Soil + Road dust	41.1	29.4	23.9	42.8	75.7
Diesel automobile	34.8	36.9	28.9	37.8	24.7
Gasoline automobile	5.6	1.9	3.5	3.6	0.2
Iron and steel Ind.	2.2	2.9	12.7	1.5	0.9
Fuel oil combustion	0.4	0.6	1.0	0.2	0.1
TOTAL	88.8	80.6	74.6	92.4	106.1

【Second survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	12.2	21.6	10.9	15.7	21.6
Soil + Road dust	41.5	14.2	15.1	34.6	39.2
Diesel automobile	32.8	29.9	28.7	48.4	34.3
Gasoline automobile	0.8	0.2	2.8	0.7	0.0
Iron and steel Ind.	2.4	1.1	4.3	1.6	0.2
Fuel oil combustion	0.3	1.8	2.7	0.3	0.1
TOTAL	90.1	68.8	64.5	101.3	95.4

【Third survey】 (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	5.1	10.0	5.8	7.4	8.4
Soil + Road dust	28.3	27.1	18.9	30.8	48.3
Diesel automobile	38.2	29.8	30.2	37.8	23.8
Gasoline automobile	3.9	0.2	1.9	2.4	0.9
Iron and steel Ind.	4.5	3.6	4.9	2.6	3.3
Fuel oil combustion	0.4	1.2	1.3	0.3	0.3
TOTAL	80.4	71.8	63.0	81.5	84.9

(5) The results of the estimation by the CMB method with 7 emission source types

The results estimated with 6 emission source types (excluding Refuse incineration) seemed suitable. However, the Sumut Prakarn industrial district there are some glass factories. So it is necessary to estimate the contribution rate of emission source type Glass industry. The chemical component composition data of Glass industry is cited from Iide et al.[36)] and the contribution rates of emission source types are estimated. The emission source matrices are shown in Table 2-11, and the results of the estimation are shown in Table 2-12.

Table 2-11 The Matrix about the Component Concentrations in Emission Sources (Refuse Incineration is Replaced by Glass Industry.)

(unit;ppm)

	Sea salt	Soil + Road dust	Diesel automobile	Gasoline automobile	Iron and steel Ind.	Fuel oil combustion	Glass industry
Al	0.3	55500	240	1300	18000	14250	26700
Br	1900	17.5	0	20000	140	60	1080
Ca	12000	1750	3260	1800	47000	14500	31700
Cr	0.001	27.5	46	21	4230	2760	5160
Fe	0.29	12000	360	4900	301000	28300	10200
K	11000	31500	120	2000	11500	1300	23100
Mn	0.058	365	77	51	27700	500	7910
Na	304200	6500	120	200	7150	37800	42300
Ni	0.014	30	0	38	1700	21000	8820
Pb	0.087	70	490	120000	10500	900	39000
Sb	0.014	1.575	0.48	1.9	90	10	1800
Sc	0.001	4.45	0	0.12	1.3	0.33	2
Se	0.12	9.2	3.0	0	48	67	683
Ti	0.029	2700	0	0	1000	430	2400
V	0.058	35.5	2.9	2.1	365	37700	830
Zn	0.029	17.5	1160	1400	26000	1700	40100
Cele	0	3250	620000	301000	33000	371000	371000
Corg	0	1000	100000	263000	33000	24000	24000

Table 2-12 The Results of the Estimation by the CMB Method (7 Sources; Refuse Incineration is Replaced by Glass Industry)

[First survey] (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	4.5	8.9	4.5	6.5	4.4
Soil + Road dust	41.0	29.3	23.8	43.1	76.2
Diesel automobile	34.8	36.8	28.5	37.8	24.5
Gasoline automobile	5.6	1.9	3.5	3.6	0.1
Iron and steel Ind.	2.1	2.7	10.7	1.8	0.3
Fuel oil combustion	0.4	0.6	0.9	0.2	0.1
Glass industry	0.1	0.1	1.0	-0.2	0.5
TOTAL	88.6	80.4	72.9	92.9	106.2

[Second survey] (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	12.2	22.6	10.7	15.8	21.3
Soil + Road dust	41.6	13.7	14.8	35.1	41.7
Diesel automobile	32.7	29.0	27.0	47.6	33.9
Gasoline automobile	0.8	-0.4	2.4	0.4	-0.2
Iron and steel Ind.	2.0	0.4	0.1	0.3	-0.7
Fuel oil combustion	0.3	1.6	2.4	0.2	0.1
Glass industry	0.4	2.0	3.7	1.4	0.7
TOTAL	89.8	68.9	61.1	100.9	96.9

[Third survey] (%)

Component	MS 1	MS 2	MS 3	MS 4	MS 5
Sea salt	5.0	9.7	5.7	7.4	8.4
Soil + Road dust	28.3	26.2	18.7	30.5	47.1
Diesel automobile	38.0	28.7	29.8	37.6	23.1
Gasoline automobile	3.8	0.1	1.9	2.4	0.5
Iron and steel Ind.	3.8	2.6	4.0	2.0	2.3
Fuel oil combustion	0.3	1.1	1.3	0.3	0.2
Glass industry	0.5	2.1	0.7	0.6	1.6
TOTAL	79.8	70.4	62.1	80.7	83.3

These results indicate that the contribution rates of Gasoline automobile (at two stations), Iron and steel industry (one station) and Glass industry (one station) are negative. And the total contribution rate is over 100% at MS5 (1st survey) and MS4 (2nd survey).

In the next place, the comparison between the calculated value and the observed value is made in order to examine the adaptability of the CMB method on each index element. The result is shown in Table 2-13.

The results that the ratios (the calculated values: the observed values) for Al, Na, V, Ni, Pb, elemental carbon and Mn are nearly 1 show the high precision of the contribution rates estimation of Soil, Sea salt, Diesel automobile, Gasoline automobile, Iron and steel industry and Fuel oil combustion. On the other hand, some ratios for Sb and Zn are low (about 0.1), so the contribution rate of Glass industry is seemed to be inaccurate.

The reason for the inferior results of this estimation—some total contribution rates are over 100%, some contribution rates are negative and the estimated values of some components are different from the observed values—seems to be in emission source matrices. This means that this estimation data by using literature departed from the actual condition at the Samut Prakarn industrial district. Anyway, some negative contribution rates can be regarded as zero, because their absolute values are very small. So these results seem to be proper.