CHAPTER 2
LITERATURE REVIEW

2.1 Preamble

The aim of this chapter is to discuss the various literatures cited in regard to air pollution prevention from a holistic view. Topics such as air pollution prevention (P2), vehicular emissions and transport models, relation between various emission sources and vehicular patters are reviewed. Further, various strategies used elsewhere in addressing the above mentioned issues are also reviewed.

2.2 Pollution Prevention (P2)

Generally, "air pollution" is a term used to describe any unwanted chemicals or other materials that contaminate the air that we breathe resulting in the degradation of air quality. The United States Pollution Prevention Act defines "pollution prevention" (P2) as "source reduction" and other practices that reduce or eliminate the creation of pollutants. Practical attributes of P2 are to 1) reduce the amount of any hazardous substances, pollutants, or contaminants entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and 2) reduce the hazards to public health and the environment caused by the release of such substances, pollutants, or contaminants (U.S.EPA, 1994).

P2 has evolved substantially since 1988, from U.S. EPA initiative and approach. These P2 tool is derived from quality programs and widely used throughout the world. EPA-defined P2 is preferable for "end-of-pipe" control. The application of the quality improvement tools used by the Systems Approach is an influential force in eliminating environmental inefficiencies and preventing pollution as demonstrated in the following steps;

- Process characterization with hierarchical process mapping,
- Resource accounting using the process maps as a template,
- Selection of P2 opportunities using a Pareto diagram with appropriate cost information,
- Analysis of the root cause of the problem using a cause-and-effect diagram,
- Generation of alternative solutions using brain writing or similar solution generating approach,
- Selection of an alternative for implementation using bubble-up/bubble-down or similar ranking approach, and
- Implementation of the alternative using an action plan.

P2 can help to characterize the process, solve problems, make decisions and make action plans for providing documentation and accomplishing the goals decided upon by using these tools (U.S.EPA, 2001).

Principle process of pollution prevention techniques of U.S. EPA had been derived on the basis of quality tools that can be successfully and widely employed throughout the world for sustainable development. It can be made through the following steps.

Step 1: Process mapping. It explains the steps that resources as the input passing through the process and are transformed into final product as the output. Process map allows an organization to identify all inputs and outputs from a process to draw up where waste, emissions and other losses evident, and leads to a better understanding of the processes. This process map can serve as templates for resource accounting and activities based costing.

Step 2: Root-cause analysis. It focuses to the nature of the problem. The user can use a cause and effect diagram that highlight why and where losses occur in a process. This information helps participants focus on specific areas for improvement. Root cause analysis promotes discussion and helps gather information on problems from a complete range of possible contributing factors, including man, methods, machines, and materials.

Step 3: Developing alternatives. Alternatives are developed by brain storming. It generates as many alternative solutions as possible for addressing how the wastes, emissions, or other losses. This step needs to produce many potential solutions, rather than focusing on a single "right" answer.

Step 4: Selecting an alternative. Decision making for alternative selection is made through discussion of all alternative solutions like "bubble-up/bubble-down". Prioritizing alternatives is evaluated to determine the optimal solution for the select to the best solution. Factors such as cost, ease of implementation, a nd effectiveness are considered in evaluating and prioritizing the alternative solutions.

Step 5: Action plans. After getting the best solution to solve the main problem is needed to be taken for action. The best solution chosen is implemented for reducing or eliminating the waste, emission, or other loss. Action plans allow organization to track progress and provide a platform against which to audit environmental excellence program implementation.

2.3 Vehicle Emissions Model

The University of California at Riverside and its College of Engineering Center for Environmental Research and Technology (CE-CERT), along with Global Sustainable Systems Research (GSSR), cooperated with the U.S. Environmental Protection Agency (EPA) in the developed and tested of the International Vehicle Emissions (IVE) model. The IVE model is specifically designed for the flexibility needs by developing countries in their efforts to address mobile source air emissions.

Previously, emissions models from the U.S. and Europe were developed reasonably accurate emissions projection, but were designed only for their respective regions. These models cannot take into account the differing technologies and conditions that are most occur in developing countries. Moreover, most of these existing models do not include the full range of global warming and local toxic emissions that are needed to fully evaluate the impact of motor vehicles.

The IVE model is a computer model designed to estimate emissions from motor vehicles in developing countries. The model will help cities and regions develop emissions estimates for: 1) Focus control strategies and transportation planning that are most effective 2) Predict how different strategies will affect local emissions and 3) Measure progress in reducing emissions over time (including local air pollutants, greenhouse gas emissions, and toxic pollutants).

The IVE model has three critical components necessary to develop accurate mobile source emissions inventories: 1) vehicle emission rates, 2) vehicle activity, and 3) vehicle fleet distribution. And the required three main data sets are; 1) fleet composition, 2) vehicle activity, and 3) emission rates. Furthermore, the IVE model is designed to use appropriate existing information and easily collectable local data to quantify these three essential inputs, and model core architectures as shown in Figure 2.1.

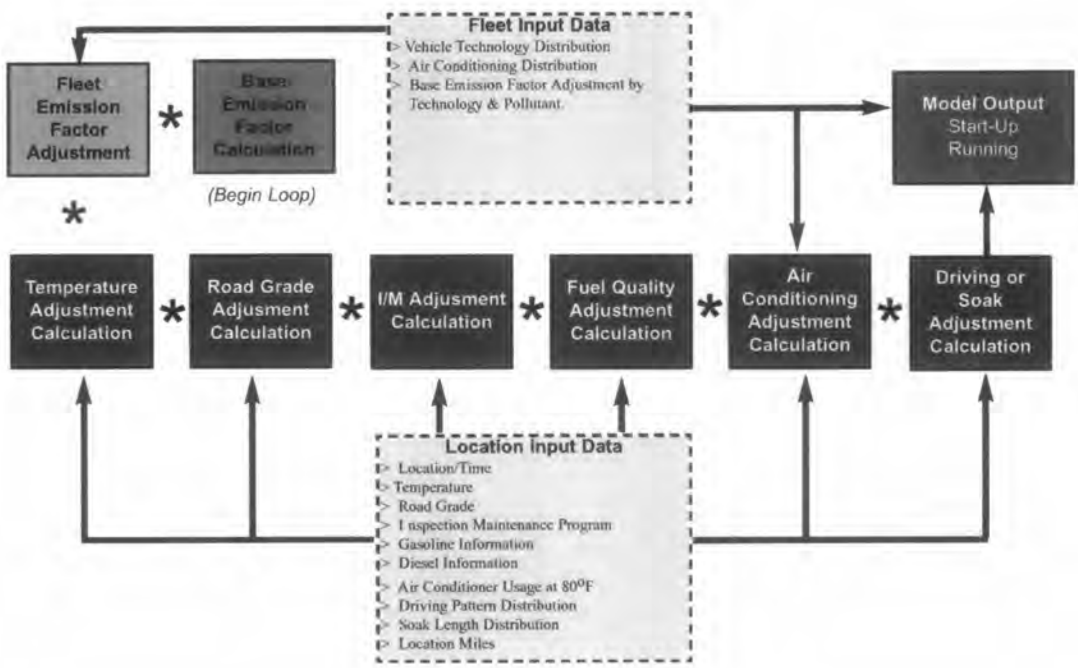

Figure 2.1 IVE-Model core architectures

The basic prediction of the base emission rate in IVE characterizes emissions with a series of correction factors to estimate the amount of pollution from a variety of vehicle types as shown in equation 1, and divides the estimates of base emission rates for running emissions in equation 2 and for start emissions in equation 3 as follows;

$$Q_{[t]} = B_{[t]} K_{(Base)[t]} K_{(Tmp)[t]} K_{(Hmd)[t]} K_{(IM)[t]} K_{(Fuel)[t]} K_{(Alt)[t]} K_{(Cntry)[t]} \quad (1)$$

$$Q_{running} = \bar{U}_{FTP} D / \bar{U}_{C} \Sigma_t \{f_{[t]} Q_{[t]} \Sigma_d [f_{[dt]} K_{[dt]}]\} \quad (2)$$

$$Q_{start} = \Sigma_t \{f_{[t]} Q_{[t]} \Sigma_d [f_{[dt]} K_{[dt]}]\} \quad (3)$$

where: $B_{[t]}$ = base emission rate for each technology (start (g) or running (g/km))

$Q_{[t]}$ = adjusted emission rate for each technology (start (g) or running (g))

Q = average emission rate for the entire fleet (start (g) or running (g))

$f_{[t]}$ = fraction of travel by a specific technology

$f_{[dt]}$ = fraction of each type of driving or soak by a specific technology

$\bar{U}_{FTP}$ = average velocity of the driving cycle (a constant (g/km))

D = distance traveled as input by user in location file (km)

$\bar{U}_{C}$ = average velocity from the specific driving cycle, as input by users in location file (kph)

$K_{(Base)[t]}$ = adjustment to the base emission rate

$K_{(Tmp)[t]}$ = temperature correction factor

$K_{(Hmd)[t]}$ = humidity correction factor

$K_{(IM)[t]}$ = inspection/maintenance correction factor

$K_{(Fuel)[t]}$ = fuel quality correction factor

$K_{(Alt)[t]}$ = altitude correction factor

$K_{(Cntry)[t]}$ = country correction factor

$K_{[dt]}$ = driving or soak style correction factor (also accounts for other load effects from air conditioning usage and road grade).

The results from IVE are an overall estimate of fleet running emissions for the allocated travel distance or travel time in grams per hour (g/hr) or in grams per kilometer (g/km) (CE-CERT, GSSR, and ISSRC, 2004).

2.4 Transport Model

In Thailand, [former the Office of the Commission for the Management of Land Traffic (OCMLT)] the Office of Transport and Traffic Policy and Planning (OTP), Ministry of Transport was developed a transport model to predict traffic conditions in Bangkok urban area for all related agencies since 1998. This model predict the traffic demand in years 2005, 2010, and 2025, which will allow further analysis of the traffic and economics in transport planning.

The structure of the transport model can be described as an interconnection of mathematical models of current traffic conditions and travel behavior and can be used for forecasting future trips following changes in urbanization, land use, socio-economic conditions, population and employment. These call four stages model as shown in Figure 2.2.

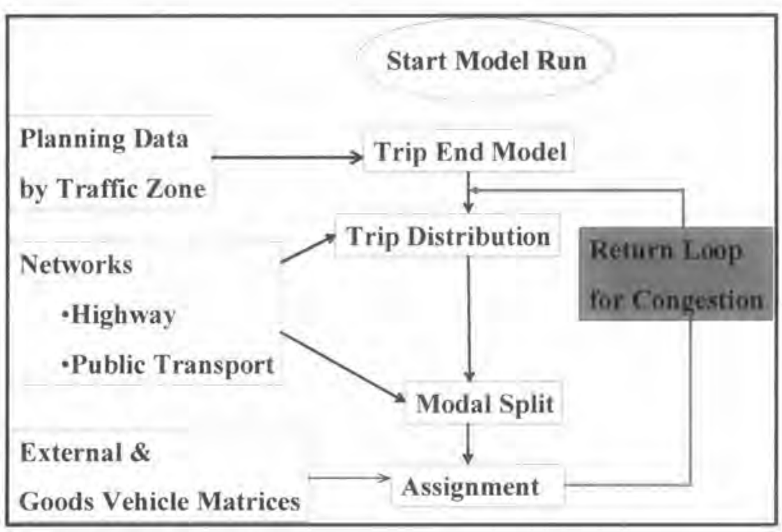

Figure 2.2 Structure of transport four stages model.

Figure 2.2 shows the transport model which has a four stages approach as follows:

- **The trip generation model** represents the relationship between trip generation at trip end and other variables of travel in each traffic zone. The relationship between the explanatory variables, such as the social and economic characteristics of the population and employment, is characterized by using a series of linear regression equations as follows;

$$Trip = \alpha + \beta Pop + \gamma Inc + \theta Emp \qquad (4)$$

where: $Trip$ = number of trips produced in each zone

Pop = number of populations in each zone

Inc = average income in each zone

Emp = number of employments in each zone

$\alpha, \beta, \gamma, \theta$ = coefficients of independent variables (e.g. elasticity of changes in populations, income, and employment).

- **The trip distribution model** is used for calculating trips from one zone to another. The result from the analysis shows the trip distribution within the study area that can be applied for forecasting of future trip distributions by using a series of linear regression equations as follows;

$$T_{ij} = a_i b_j P_i A_j F(C_{ij}) K_{ij} \qquad (5)$$

where: T_{ij} = total trips going from zone i to zone j

P_i = trip productions in zone i

A_j = trip attractions in zone j

$A_i\, b_j$ = coefficients

$F(C_{ij})$ = function of travel costs from zone i to zone j

K_{ij} = the adjustment factor for trips going from zone i to zone j

(e.g. socioeconomic adjustment factor).

- **The modal split model** is used to determine the proportion of trips using private and public transportation modes. The result from the analysis can be used for forecasting of future travel by various modes enabling planners to lay down suitable traffic and transport plans by binomial (two alternatives) logit model as following;

$$P_{ijk} = 1 / (1+\{exp(\alpha(C_{ij}) + \delta\}) \qquad (6)$$

where: P_{ijk} = proportion of travel by k between zone i to zone j

C_{ij} = differential of travel cost between private car and public transport

α = legit curve (alpha)

δ = bias valuation of public transport (delta).

- **The traffic assignment model** determines the routes and services used for trips based on a relationship between speed and volume of traffic and road capacity represented in generalized cost of travel by a linear regression equation as follows;

$$GC = aTime + bDistance + cToll \quad (7)$$

where: GC = generalized cost of total travel

$Time$ = total travel time

$Distance$ = total distance of travel

$Toll$ = expense toll

a, b, c = coefficients for changing the other value to value of time or value of cost.

The output of the transport model is presented in terms of vehicle-kilometers travelled (VKT), vehicle-hours travelled (VHT), and speeds (OTP, 2005). U.S. Department of Transport (1997) has maximum acceptable error from travel model improvement as shown in Table 2.1.

Table 2.1 Maximum acceptable error of travel model improvement

Travel Volume (PCU/day)	Percent Diff.
0 - 5,000	± 36
5,000 - 10,000	± 29
10,000 - 25,000	± 25
25,000 - 50,000	± 22
> 50,000	± 21

Source: Travel Model Improvement Program, Federal Highway Administration, U.S. Department of Transportation (1997)

2.5 Relationship between the traffic conditions and pollution emissions levels

Emission levels from transportation sources are function of several variables such as: emissions are a function of trip distance traveled, emission levels depend on speed and acceleration of the vehicle and the load on the engine over the distance of the trip, emissions are affected by driving behavior and traffic conditions, and are affected by the physical characteristics of the roadway network (Radian, 1994).

2.6 Multi-Criteria Analysis Techniques

All Multi-Criteria Analysis (MCA) approaches make the options and their contributions to the different criteria explicit, and all require the exercise of judgment. They differ, however, in how they combine the data. The formal MCA techniques usually provide an explicit relative weighting system for the different criteria. The main role of the techniques is to deal with the difficulties that human decision-makers have been shown in handling large amounts of complex information in a consistent way (Thomas L. Saaty (1980).

The MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from the unacceptable possibilities.

As it is clear from a growing literature, there are many MCA techniques and their number is still rising. There are several reasons why this is so:

- There are many different types of decision which fit the broad circumstances of MCA,

- The time available to undertake the analysis may vary,

- The amount or nature of data available to support the analysis may vary;

- The analytical skills of those supporting the decision may vary; and

- The administrative culture and requirements of organizations vary.

Accordingly, two broad classes of multi-criteria analysis (MCA) can be distinguished: MADM (multi-attribute decision making) and MODM (multi-objective decision making). Both MADM and MODM problems are further categorized into single decision maker problems and group decision problems. These two categories are, in turn, subdivided into deterministic and stochastic decisions. Deterministic decision problems assume that the required data and information are known with certainty and that there is a known deterministic relationship between every decision and the corresponding decision consequence. Stochastic (probabilistic) analysis deals with a decision situation under uncertainty about the state of problem's environment and about the relationships between the decision and its consequences. These practical techniques, and indicates the types of application in this study used the Analytic Hierarchy Process (AHP) and Fuzzy system for decision the priority problem and alternative solutions as the following techniques.

2.7 The Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is an extensively used method in decision-making. At the core of the AHP lies a method for converting subjective assessments of relative importance to a set of overall scores or weights. The method was originally devised by Thomas L. Saaty (1980). It has proved to be one of the widely applied methods for summaries of applications.

AHP is used to determine the final weight for each of the criteria by stating the problem and identifying the criteria that influence the conduct of the problem, next forming a hierarchy of the criteria, and then assembling the pair wise comparison matrix for the primary criteria with respect to their impact on the overall objective by converting the preferences to quantitative values using the scale designed by Thomas L. Saaty (1980), to be compared within the AHP scale, 1 to 9, (e.g. 1 = no importance, 2 = weak, 3 = moderate, 4 moderate plus, 5 = strong importance, 6 = strong plus, 7 = very strong, 8 = very, very strong, and 9 = extreme importance).

Later, the approach computes priorities of criteria (calculation of the priority weight vectors) and tests the consistency index (C.I.), and tests the consistency ratio (C.R.) for the entire hierarchy, thereby providing comparison matrices of the criteria level.

The major work of AHP is the estimation of the weights of a set of subjects (criteria) from a matrix of pair wise comparisons (A = (aij)) by entries aij in the matrix A that are based on the 1-9 interval scale was originally devised by Yung-Jye Sha and Zhen-Hua Che (2003) as follows;

$$A=\left[a_{ij}\right]=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix} \quad (8)$$

where: A = reciprocal and square pair wise comparison matrix (Represented by n x n matrix A)

a = criteria (e.g. comfort, price)

a_{ij} = 1/aji for all i, j = 1, 2,..., n.

For expressing the relative degree between decision criteria, the priority vector (eigenvector) is solved by use of an eigenvalue method. The main eigenvector could be calculated and becomes the priority vector when normalized. The formula for obtaining the eigenvector as following;

$$Aw = \lambda\max \ w \quad (9)$$

where: $\lambda\max$ = the largest Eigen value of A

w = the eigenvector.

For testing consistency from each comparison matrix and hierarchy architecture, the consistency index (CI) and consistency ratio (CR) would be computed and defined in equations 10 and 11 as follows;

$$CI = (\lambda \max - n)/(n-1) \quad (10)$$

$$CR = CI/RI \quad (11)$$

where: RI = random index

n = number of compared-criteria

2.8 The Fuzzy system

Fuzzy system that was conceptualized by Zadeh in the 1960s, is broadly equivalent to the sets found in conventional mathematics and probability theory with one important exception. The fuzzy system tries to capture the idea that our natural language in discussing issues is not precise. Options are "fairly attractive" from a particular point of view or "rather fair", not simply "attractive" or "fair". Fuzzy arithmetic then tries to capture these qualified assessments using the idea of a membership function, through which solutions would belong to the set of the best solution with a given degree of membership, lying between 0 and 1.

Fuzzy decision making will break the decision scenario down into small parts that can focus and indication is given as to which alternative solution is the best within the constraints and goals of the particular solutions (F. Martin McNeill, 1994). And automobile controls can be used as fuzzy systems for estimating and decision-making (F. Martin McNeill and Ellen Thro, 1998).

The fuzzy methodology is an extension of Saaty's priority theory by using the mathematical approach for evaluation of a set of subjects (alternatives) having two finite suggestion sets, (Xumei Chen and Guoxin Lin, 2005) and can be expressed as follows;

$$U = \{u1, u2, \ldots, um\} \text{ and } V = \{v1, v2, \ldots, vn\} \tag{12}$$

where: U = set of evaluation factors (e.g. convenience, change of cost)

V = set of evaluations (e.g. v1 = excellent, v2 = good).

Fuzzy comprehensive evaluation for decision making by equations as follows;

$$B = A \circ R \tag{13}$$

where: A = fuzzy subset on U (weight vector of U)

B = evaluation result

R = fuzzy relation on U x V.

Transformation of linguistic terms to fuzzy numbers

Chen and Hwang (1992) introduced an approximation system (the conversion scales) to systematically transform linguistic terms (e.g. very low, low, medium, high or very high) to their corresponding fuzzy numbers the approximation system is composed of the systematic five scales. All linguistic terms contained in each conversion scale are presented in Table 2.2 and for all illustration purpose, two of these conversion scales are shown in Figure 2.3 the conversion scales were derived from the synthesis and modification of various studies.

Table 2.2 Summary of linguistic terms used in each conversion system

Scales	1	2	3	4	5
Very low	X	X	X	X	X
Low				X	X
Medium	X	X	X	X	X
High		X	X	X	X
Very high					X
No. of terms used	2	3	3	4	5

Source: Adapted from Chen and Hwang (1992), p.470

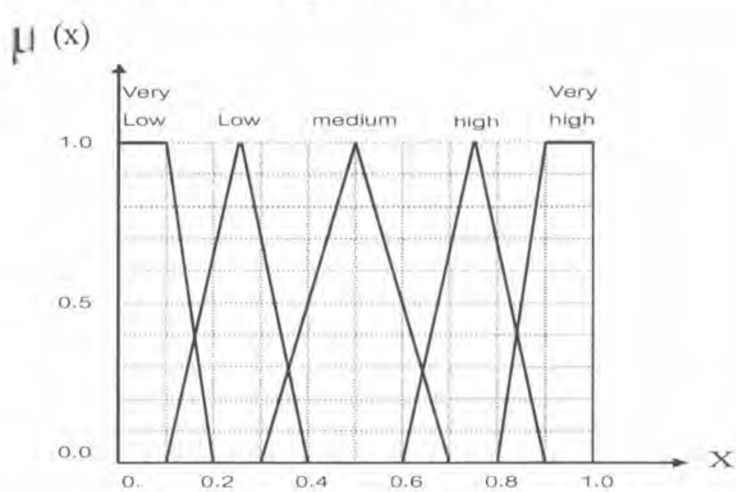

Figure 2.3 A scale for five linguistic terms

The advantages of AHP and Fuzzy allow the approaches to be used to study how the uncertainty in classification is made clear, enable the direct participation of experts in determining variable weights and the variable weights can be adjusted to reflect different impacts such as environmental impacts, economic impacts, implementation impacts and social impacts. Moreover, the AHP/Fuzzy approach can also successfully identify differences in criteria within each case study and identify factors contributing to sensitivity and capacity. Finally, it is a flexible methodology because the variables can be changed to suit criteria, and factors allow comparison within and between case studies or scenarios (Mónica B. Wehbe and Hallie C. Eakin, 2004)

2.9 Air pollution estimation

Hanson and Lopez (1992) estimated the emission factors by fuel and vehicle combination related to generation of carbon monoxide (CO) in Bangkok.

In 1994, the Radian Corporation, under a contract with the Pollution Control Department (PCD), was conducted "Motor Vehicle Pollution Control in Bangkok: A Strategy for Progress", which studied on an emission database for input into the MOBILE program. The results from the MOBILE model can be updated and used to calculate the emission factors of each pollutant. The road network and the traffic data cover the hourly volume, traffic composition, speed, and the average daily traffic (ADT)

(PCD, 1994) whereas the emission from on-road vehicles can be determined from the vehicle kilometer travelled (VKT) and the emission factors of pollutants.

The emission factors of nitrogen oxide (NOx) were developed by Boontherawara et al. (1994). These emission factors depend on the ambient air temperature, vapor pressure, speed, operating mode, altitude, model year (age of vehicle), and so on.

Tanadtang (1999) conducted a study to investigate the effects of traffic on the air quality through driving cycle tests by measure and evaluate the exhaust emissions of gasoline-powered vehicles over the congested and non-congested roads, suburban roads and expressways in Bangkok.

Muttamara and Leong (2000) measured the exhaust emission from gasoline-powered motor vehicles in Bangkok on a chassis dynamometer. The results indicated that the air pollutant emissions significantly increase with the more of car mileage and age of model year. The findings also revealed that there was a correlation between the average air pollution concentrations and the average traffic speed in each traffic zone in the Bangkok Metropolitan area and Region.

2.10 Air quality monitoring in Bangkok

Air quality in Bangkok has been measured by the PCD from an off-street network and with roadside display boards. The off-street monitoring stations indicate that the air quality for the general populations at work, study or rest. The populations in Bangkok spend large amounts of time on the streets. For example, taxi and bus drivers, motorcyclists, and the average commuters, who may have to spend two to four hours on the streets every day. It is thus appropriate to use the air quality at the worst case, which are from the roadside air monitoring data by the Pollution Control Department's stations, which can provide available data for the past ten years (PCD, 2004).

2.11 Air pollution effects

Pollutants from vehicles are harmful to health and destroy the quality of life. With regard to health especially, motor vehicles emitted large quantities of carbon monoxide, hydrocarbons, nitrogen oxides, and such toxic substances as fine particles and lead. Each of these can cause adverse effects on human health and the environment. Because of the growing vehicle populations and the high emission rates, serious air pollution problems have been increasingly common phenomena in Bangkok (Radian, 1994).

Air pollution or toxic air pollutants, are also known as hazardous air pollutants (HAPs). About one-half of the HAPs listed in the United States Clean Air Act can cause many acute and chronic diseases in humans exposed to them such as reproductive effects or birth defects, or adverse environmental effects (U.S.EPA, 1996).

Mobile sources (traffic) represent the main sources of air pollution. Traffic is a large contributor to air emissions in cities with frequent traffic congestion and with large, poorly maintained fleets of vehicles that use high-sulfur diesel fuel (e.g. in Asia). In cities, traffic may contribute 80–90% of air pollutants (World Bank, 1998).

2.12 Major air pollutants

Carbon monoxide

Carbon monoxide (CO) is a non-irritating, tasteless, colorless, and odorless gas produced by incomplete combustion of any carbon containing material. In transport, human exposure to the pollutant occurs through the inhalation of smoke from automobile exhaust fumes. Motor vehicles are responsible for 75% of the carbon monoxide emissions in Bangkok (PCD, 2004).

Exposure to carbon monoxide results primarily from vehicle emissions. Because the affinity of hemoglobin in the blood is 200 times greater for carbon monoxide than for oxygen, carbon monoxide hinders oxygen transport from blood into the tissues. Therefore, more blood must be pumped to deliver the same amount of oxygen (Wark et al, 1998).

Scientific studies in humans and animals have demonstrated that subjects with weak hearts are placed under additional strain by the presence of excess CO in the blood. For example, an assessment by the Health Effects Institute indicated that low levels of CO produce significant effects on cardiac function during exercise in subjects with coronary artery disease. In addition, fetuses, sickle cell victims and young children may also be especially susceptible to low exposure levels of CO (Wark et al, 1998).

Hydrocarbons

Hydrocarbon (HC) emissions result when fuel molecules in the engine do not burn even partially. Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground level ozone, a major component of smog. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems. It is the most widespread and intractable urban air pollution problem. A number of exhaust hydrocarbons are also toxic and carcinogenic (U.S.EPA, 1994).

The Flame Ionization method (particularly in conjunction with gas chromatography) can be used for analysis of hydrocarbons with a flame ionization detector (FID). Here the hydrocarbons are burnt in a hydrogen flame across which is applied a potential difference. Ionization current is set up across the electrodes, which is proportional to the concentration of the hydrocarbons (Wark et al, 1998).

Nitrogen oxide

NO_x emissions in Bangkok are relatively low; however the main source of nitrogen oxide is the transport sector, accounting for 80% of total emissions (PCD, 2000). NO_x causes a wide variety of health and environmental impacts because of various compounds and derivatives in the family of nitrogen oxides, including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide (U.S.EPA, 1994).

Exposure to nitrogen dioxide (NO2) emissions is linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function. Short-term exposures to NO2 have resulted in a wide-ranging group of respiratory problems in school children (cough, running nose and sore throat are among the most common) as well as increased sensitivity to urban dust and pollen by asthmatics (Wark et al, 1998).

Particulate Matter

Particulate Matter (PM) is a complex mixture of organic and inorganic substances, present in the atmosphere as both liquids and solids. Particulate matter is emitted from human activities or man-made sources, the most significant primary sources are from road traffic and non-combustion processes. Natural sources are less important, these include volcanoes and dust storms. Fine particles of less than 10 micrometer in diameter can penetrate deep into the lung and cause more human health damage (U.S.EPA, 2004).

Motor vehicles generate a significant percentage of totals Particulate matter (PM) pollution, especially the most dangerous particulates which are both toxic and very small. Diesel engines and 2-stroke motorcycles account for more of all vehicle-related

PM emissions. Gasoline and LPG-powered cars, while very numerous, produce only low levels of PM. (PCD, 2004) the PM emissions by each mobile source is shown in Table 2.3.

Table 2.3 Total PM emission by type of vehicle in Bangkok

Vehicle Type	Average Annual km	Number of Vehicle	PM Emission Rate (g/km)	Annual PM Emissions (tons/year)	Share of Total PM Emissions (%)
City Bus	97,525	24,928	1.855	4,510	31
City Trucks	16,000	67,253	1.855	1,996	14
Long Haul	12,000	31,819	1.855	706	5
Light Duty	18,075	664,080	0.398	4,777	33
Passenger Car	17,171	1,317,062	0.005	113	1
Motorcycle	10,000	1,660,119	0.150	2,490	17
TOTAL				14,595	

Source: Air Quality Management Report, 2004, PCD.

2.13 Air pollution standards in Thailand

The Pollution Control Department (PCD), Thailand establishes air pollution standards for Thailand. First, the Ambient Air Quality Standards of Thailand has been developed from the National Ambient Air Quality Standards (NAASs) of U.S.EPA as shown in Table 2.4.

Table 2.4 Ambient air quality standards in Thailand (1995)

Pollutant (25° C)	Time					Method of Measurement
	1-hr	8-hr	24-hr	1-month	1-year	
CO	34.2 (30)	10.26 (9)				Non-Dispersive IR Detection
NO_2	0.32 (0.17)					Chemiluminescence
SO_2	0.78 (0.3)		0.3 (0.12)		0.1 (0.01)	UV Fluo rescence
TSP			0.33		0.1	Gravimetric High Volume
PM10			0.12		0.05	Gravimetric High Volume
O_3	0.2 (0.1)					Chemiluminescence
Pb				0.0015		Atomic Absorption Spectrometer

Source: PCD (1998)

Note: unit mg/m^3 (ppm)

Second, the emission standards for motor vehicles in Thailand have been set for different types of motor vehicles by PCD. The updated standards (PCD, 1999, 2004) for each type of motor vehicles are shown in Tables 2.5-2.8.

Table 2.5 Emission standards for motor vehicle in Thailand: gasoline engine vehicles

Standard No.	Level	Reference Standard	Vehicle Type	CO (g/km)	HC+NOx (g/km)	Enforced
TIS. 1365-1996	4	93/59/EEC	PC<6 seat	2.72	0.97	01/01/1997
TIS. 1365-1996	4	93/59/EEC	PC>6 seat	2.72-6.90	0.97-1.70	01/01/1997
TIS. 1440-1997	5	94/12/EC	PC<6 seat	2.20	0.50	01/01/1999
TIS. 1440-1997	5	94/12/EC	PC>6 seat	2.72-6.90	0.97-1.70	01/01/1999

Table 2.5 (*Cont.*) Emission standards for motor vehicle in Thailand: gasoline engine vehicles

Standard No.	Level	Reference Standard	Vehicle Type	CO (g/km)	HC + NO_x (g/km)	Enforced
TIS.2155-2003	7	RW <2,500	PC<6 seat	2.3	HC = 0.20	10/01/2005
TIS.2155-2003	7	RW <2,500	PC>6 seat	2.3	HC = 0.20	10/01/2005
TIS.2155-2003	7	RW 1,305 - 1,760	PC>6 seat	4.17	HC = 0.25	10/01/2005
TIS.2155-2003	7	RW >1,760	PC>6 seat	5.22	HC = 0.29	10/01/2005

Source: PCD (1999, 2004)

Table 2.6 Emission standards for motor vehicles in Thailand: light duty diesel engine

Standard No.	Level	Reference Standard	Vehicle Type	CO (g/km)	HC+NO_x (g/km)	PM (g/km)	Enforced
TIS.1370-1996	3	93/59/EEC	PC<6 seat	2.72	0.97	0.14	01/01/1997
TIS.1370-1996	3	93/59/EEC	PC>6 seat	2.72-6.90	0.97-1.70	0.14-0.25	01/01/1997
TIS.1440-1997	4	94/12/EC	PC<6 seat	1.00	0.70	0.08	01/01/1999
TIS.1440-1997	4	94/12/EC	PC>6 seat	2.72-6.90	0.97-1.70	0.14-0.25	01/01/1999
TIS.2155-2003	6	RW <2,500	PC<6seat	0.64	0.56	0.05	10/01/2005
TIS.2155-2003	6	RW <2,500	PC>6 seat	0.64	0.56	0.05	10/01/2005
TIS.2155-2003	6	RW 1,305 - 1,760	PC>6 seat	0.80	0.72	0.07	10/01/2005
TIS.2155-2003	6	RW >1,760	PC>6 seat	0.95	0.86	0.10	10/01/2005

Source: PCD (1999, 2004)

Table 2.7 Emission Standards for Motor Vehicles in Thailand: heavy duty diesel engine.

Standard No.	Level	Reference Standard	Vehicle Type	CO (g/km)	HC (g/km)	NOx (g/km)	PM (g/km)	Enforced
TIS.1290-1995	2	EURO I	> 9 seat	4.5	1.1	8.0	0.36	12/05/1995
TIS.1295-1998	3	EURO II	> 9 seat	4.0	1.1	7.0	0.15	01/01/1999

Source: PCD (1999, 2004)

Table 2.8 Emission standards for motor vehicles in Thailand: motorcycle

Standard No.	Reference Standard	Vehicle Type	CO (g/km)	HC (g/km)	HC +NOx (g/km)	White Smoke (%)	Evapo-ration (g/test)	Enforced
TIS.1360-1996	ECE R40-01 (Level 3)	All type	13.0	5.0	-	-	-	01/07/1997
TIS.1360-2001	Level 4	< 125 cc	4.5	-	3.0	15.0	2.0	01/07/2001
TIS.2130-2004	Level 5	<110 cc	3.5	-	2	15.0	<2.0	01/07/2004

Source: PCD (1999, 2004)

2.14 Developed emissions model in Thailand

The Pollution Control Department and Radian Corporation (1994) had developed the MOBILE5a-THAI model to predict emission pollution from 1993 to 2010 for the Bangkok Area. The structure of the MOBILE5a-THAI model can be simplified to the following five core components, which are 1) Base emission rates (BERs), 2) Fleet characteristics, 3) Correction factors, 4) Fuel characteristics, and 5) Emission control programs.

The modelling approach that used in emission factor models is centered on the base emission rates (BERs). These basic emission rates for each model year, pollutant type, and emission producing process are developed separately for the eight classes of vehicles (Radian, 1994), as follows;

- Light duty gasoline vehicles (LDGV),
- Taxis (gasoline, LPG; TAXIS),
- Light duty gasoline trucks (LDGT),
- Light duty diesel vehicles (LDDV),
- Light duty diesel trucks (LDDT),
- Heavy duty gasoline vehicles (HDGV),
- Heavy duty diesel vehicles (HDDV),
- Motorcycles (2 stroke, 4 stroke, tuk-tuks, MC).

2.15 Emission factor model components

The relationship between the five core components and the fleet average emission factor for a vehicle class, calendar year, pollutant, and emission producing process (e.g. exhaust, evaporative) can be described by the following equation;

$$EF_{i,j,k} = \sum_{m=1}^{n} VKT_{m} \times \left(BER_{j,k,m} \times CF_{j,k,m,...}\right) \qquad (14)$$

where: $EF_{i,j,k}$ = fleet-average emission factor for calendar year I, pollutant j, and process k (e.g. exhaust, evaporation);

VKT_m = fractional VKT attributed to model year m

$BER_{j,k,m}$ = base emission rate for pollutant j, process k, and model m

$CF_{j,k,m}$ = correction factor(s) (e.g., temperature, speed) for pollutant j, process k, model year m, etc.

Base Emission Rates (BERs)

U.S.EPA (2004), assumes that 43 percent of all starts are cold starts and 57 percent are hot starts which accounts for the 0.43 and 0.57 terms in the equation. The base emission rates resulting from tests conducted according to the Federal Test Procedure (FTP) can be calculated based on the following equation;

$$BER = 0.206 \times \textit{cold start} + 0.521 \times \textit{stabilized} + 0.273 \times \textit{hot start} \qquad (15)$$

The base emission rates characterize emissions for a specific model year vehicle fleet and vehicle class. The age distribution and the rate of mileage accumulation within each vehicle class can significantly affect the average rate of vehicle emissions. Additionally, the mix of travel between vehicle classes impacts the rate of emissions and must also be accounted for in the composite emission factors. MOBILE uses national average values for these parameters as defaults. However, the user has the option of employing data more representative to local conditions. MOBILE5A-THAI assumes that 25 model years of vehicles comprise the fleet. The following equation is used to calculate the VKT fraction for each of the model years;

$$\sum_{REG_m \times KM_m}^{n} REG_m \times KM_m \qquad (16)$$

where: KM_m = annual mileage accumulation for each model year *m*

REG_m = registration fraction for the model year *m*

n = total number of model years in the fleet.

Fleet characteristics

The MOBILE model produces emission factors for the following eight classes of vehicles. The emission factor for each individual class is actually a composite emission factor though it is not called that. These eight class specific emission factors represent all the vehicle makes and models in their class. For example the emission factor for light duty gasoline vehicles represents all makes of gasoline fueled passenger cars including Chevrolet, Ford, Chrysler, Toyota, etc. of all ages that are assumed to be operating in the analysis year. "Composite emission factors" are defined in the MOBILE model as the sum of the eight vehicle class emission factors weighted by the respective VKT mix fraction (U.S.EPA, 2004).

Correction factors

U.S.EPA (2004), the emissions tests which produce the BERs are performed under the same standard conditions. Thus, these base emission rates must be adjusted or corrected to be a good representation of emissions that would result from vehicles operating under conditions different from those in the standard tests. Emission factors are developed by multiplying the BERs by a series of correction factors including temperature, operating mode, and speed. The actual calculations involved are complex but can be represented by the following equation:

$$CF = TCF \times OMCF \times SCF \tag{17}$$

$$EF = BER \times TCF \times OMCF \times SCF \tag{18}$$

where: *EF* = emission factor (g/km) corrected for operating mode, temperature, and speed.

BER = composite FTP based emission rate (g/km)

TCF = temperature correction factor

OMCF = operating mode correction factor

SCF = speed correction factor

Temperature correction factors

Temperature is an important factor in determining the emission rates for all three pollutants including hydrocarbon, nitrogen oxide and particulate matter. The tests conducted under the FTP must be performed within a temperature range of 68 to 86 °F (20 to 30 °C). For any temperature outside this range, the model will apply the appropriate correction factors to the BERs. The input data for the temperature and the correction factors are specified by U.S. EPA.

At present, PCD use MOBILE 6 emission models. MOBILE 6 is currently used in the United States where it is the most widely used approach to predict air emission. The structure of the models is the same in that the activity specific emission rates estimated by the models are multiplied by emissions produced from vehicle activities to provide emission outputs by pollutant, although some of the detailed data assumptions are different (U.S.EPA, 2004).

2.16 Component of emissions pollution

The three primary pollutants associated with motor vehicles (HC, CO, NO_x) were present in demand model. Developing quantitative estimates of these pollutants requires an understanding of how they are produced. These pollutants can be linked to two fundamentally different emission producing processes and two different motor vehicle systems (combustion, exhaust system, evaporation and fuel storage and delivery system) as shown in Figure 2.4 (U.S.EPA, 2004).

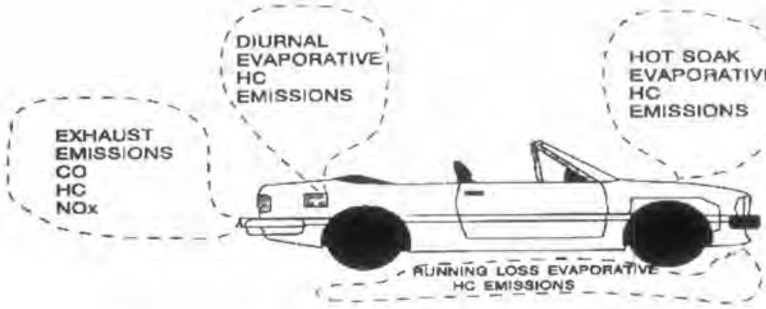

Figure 2.4 Motor vehicle emission sources

2.17 Motor vehicle emission - exhaust emissions

Exhaust emissions are commonly referred to as "tail pipe" emissions. Carbon monoxide, Oxides of Nitrogen, and Hydrocarbon emissions are all products of the combustion of fossil fuels within a vehicle's engine. However, each pollutant is produced in a different manner. Various compounds of nitrogen and oxygen are formed as a result of the high temperatures associated with combustion. Carbon monoxide is a by-product of the combustion process and actually results in the incomplete combustion of the organic fuels. Finally, the hydrocarbon emissions result from the unburned portion of the fuel that escapes through the exhaust system of the vehicle as shown in Figure 2.5 (U.S.EPA, 2004).

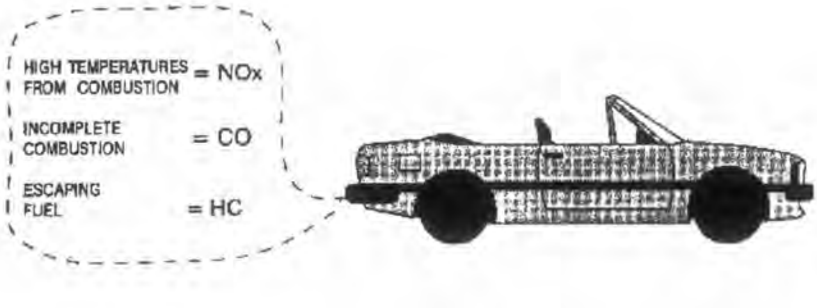

Figure 2.5 Motor vehicle emissions - exhaust emissions

2.18 Motor Vehicle Emissions - Evaporative Emissions

U.S.EPA (2004), recommend the evaporative emissions consist only of hydrocarbons. They escape from a number of locations in the fuel storage and delivery system in quantities that are highly dependent on temperature. The MOBILE model addresses the following 6 categories of evaporative emissions as shown in Figure 2.6.

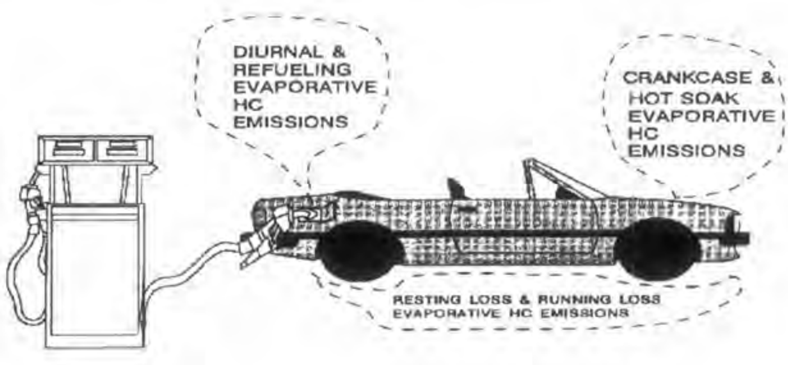

Figure 2.6 Evaporative emissions

Hot Soak - Emissions from the carburetor or fuel injector occurring when the engine is turned off;

Diurnal - Results from the "breathing" of the gasoline tank due to temperature fluctuations over the 24-hours in a day;

Running losses - Emissions loses that occur while the vehicle is being operated. They result when more fuel is emitted into the emissions control canister than is being purged from it;

Resting losses - Emissions that result from vapor permeating the evaporative emission control system or from liquid fuel leaks;

Refueling losses - There are two components, vapor space displacement and spillage both of which occur while a vehicle is being refueled;

Crankcase emissions - Not true evaporative emissions, but are defined as those that result from defective positive crankcase ventilation valves.

2.19 Sources of air pollutions

The Pollution Control Department conducted the study to determine the emissions of a particular pollutant are referred to an emission inventory (PCD, 2004). Emission factors are defined as the typical emissions that are emitted by a particular source type based on the specific pollutant, type of process, age, size, type of control technology, and other factors affecting the emissions from the source. Table 2.9 shows the emission of air pollutants from three major sources that are point (industries), line (transportation including gasoline and diesel) and area (residential) sources of Bangkok in 2003 (PCD, 2004). From the study, NO_x is 329,161 tons per year, SO_2 is 240,016 tons per year, CO is 463,775 tons per year, PM is 38,192 tons per year, VOC is 35,909 tons per year, HC is 232,973 tons per year, and CH_4 is 177,370 tons per year. Ratio of emissions pollution depend on sources as presented in Table 2.10, for example, line (transportation) source is main pollution emission as 80 percent NO_x, 75 percent CO, 54 percent PM , and 100 percent HC.

Table 2.9 Emission of air pollutants by sources in Bangkok: 2003

Source	Emission of Air Pollutants (Tons/Year)						
	NO_X	SO_2	CO	PM	VOC	HC	CH_4
Point	56,002	229,859	6,266	3,735	2,005	-	-
Line							
Gasoline	34,133	4,250	134,311	701	-	35,886	-
Light-duty diesel	65,836	1,868	34,821	6,366	-	15,739	-
Heavy-duty diesel	163,703	3,068	68,331	10,663	-	17,671	-
Motorcycle	976	786	112,308	2,871	-	163,677	-
Total	264,648	9,973	349,771	20,602	-	232,973	-
Area	8,511	184	107,738	13,855	33,904	-	177,370
Total	329,161	240,016	463,775	38,192	35,909	232,973	177,370

Source: PCD (2004)

Table 2.10 Ratio of emission of air pollutants by sources in Bangkok: 2003

Source	Percent (%)						
	NO_X	SO_2	CO	PM	VOC	HC	CH_4
Point	17.01	95.77	1.35	9.78	5.58	-	-
Line							
Gasoline	12.90				-	15.40	-
Light-duty diesel	24.88				-	6.76	-
Heavy-duty diesel	61.86				-	7.58	-

Table 2.10 (Cont) Ratio of emission of air pollutants by sources in Bangkok: 2003

Source	Percent (%)						
	NO_X	SO_2	CO	PM	VOC	HC	CH_4
Motorcycle	0.37				-	70.26	-
Total	80.40	4.15	75.42	53.94	-	100.00	-
Area	2.59	0.08	23.23	36.28	94.42	-	100.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: PCD (2004)

2.20 Proposed actions for air pollution prevention

Roger Gorham (2002), recommends the five main strategic approaches to reducing air emissions from ground transport pollutants for the international community including 1) Technical strategies approaches 2) Vehicle technology 3) Fuel technology 4) System strategies and 5) Behavioral strategies. In 2003, the Asian Development Bank formulates policy guidelines for reducing vehicle emissions in Asia consisting of four areas 1) Cleaner fuels 2) Cleaner two and three wheeler vehicles 3) Vehicle emissions standards and inspection and maintenance and 4) Transport planning and traffic management for better air quality.

In Thailand OTP (2004), has more consideration with the air pollution from the transport sector by implementing an alternative fuels system approach for setting fuel standards that requires conventional fuels to reduce their negative impacts and utilizes alternative fuels, reviews and refines the transport master plan, conducts development of public transport, provides incentives for the existing inspection and maintenance program (I/M program) for all vehicles, and encourages the development of vehicle standards and technology including the development of infrastructure to support the new changes. PCD (2004) focuses on fine PM in Bangkok by suggested improvements of air pollutants from the transport sector such as improve public transport and traffic management by increase the number of priority bus lanes, control smoke emissions from buses, and encourage the use of mass rapid transit.

Praditphet P., Watts D., and Fukuda T., (1996), propose possible solutions to reduce the levels of CO_2 from transportation sector in Bangkok, which have to consider the air emissions standards through the proposed possible solution with other significant factors. It can be divided into 5 groups as follow;

1) Alternative fuels

Implementing alternative fuels system approach for setting fuels standards requires conventional fuels to reduce their negative impacts and the increasing important role that can be done by utilizing alternative fuels in the following manners;

- Support implementation of pollutants phase-out program for fuels
- Reduce the contain of pollutants or substance in fuels
- Promote gases fuels such as CNG & LPG
- Introduce bio-diesel as alternative fuels that produce from palm, coconut, sunflower, wasted cooking oil and etc.

- Establish sound fuel pricing method & subsidy by government.
- Explore options for reformulated gasoline (RFG)

2) Transport planning and land use management

Transport planning is a key component of a comprehensive strategy to reduce air emissions from transportation sector and integrate approach is requiring which included the items below;

- Review and refine transport master plan
- Conduct development of public transport
- Establish good governance in transportation
- Encourage to use of non-motorized transport (NMT)
- Integrate transport & land use planning and management

3) Inspection and maintenance (I/M) program

I/M program should be design for more comprehensive and address to varieties of important aspects from inception as follow;

- Develop a new government regulation on air pollution control
- Develop I/M program for private vehicles at national level
- Develop advanced technology to measure effectiveness
- Incentive existing the I/M for heavy duty truck & public transport vehicles
- Strengthen I/M implementation
- Enhance existing I/M test for public transport vehicles

- Improve/Develop new inspection technology

4) Vehicle standard & technology

New vehicle standards how to closely link to fuels quality requirement, as more advanced technologies precluded or diminished by certain fuel parameters such as lead in gasoline or high sulfur levels in gasoline or diesel. In setting new vehicle standard, it should be done by the following methods;

- Issue type approval emission standards for new vehicle
- Revise in-use emission standards and fuel specification
- Conduct public awareness on related issues
- Develop infrastructure to support the new change
- Introduce catalytic converter and diesel traps

5) Public transport development

Public Transport development should be done by the following methods;

- Revise mass rapid transit network and reroute the bus system
- Common ticketing system
- Improve level of service
- Improve fare structure