การประเมินมลภาวะอากาศจากการคมนาคมขนส่ง
ในเขตเทศบาลนครราชสีมา

นายสงวน โกษารักษ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิชาวิศวกรรมสิ่งแวดล้อม

มหาวิทยาลัยเทคโนโลยีสุรนารี

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AIR POLLUTION ASSESSMENT IN TRANSPORTATION SECTOR IN NAKHON RATCHASIMA MUNICIPALITY

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สงวน โกษารักษ์ : การประเมินมลภาวะอากาศจากการคมนาคมขนส่งในเขตเทศบาลนครราชสีมา (AIR POLLUTION ASSESSMENT IN TRANSPORTATTION SECTOR IN NAKHON RATCHASIMA MUNICIPALITY)
อาจารย์ที่ปรึกษา : Assist. Prof. Dr. Ram Sharma Tiwaree, 122 หน้า

ในการขยายตัวของภาคอุตสาหกรรม ได้ส่งผลกระทบต่อความเป็นอยู่ภายในชุมชนเมือง เป็นต้นว่าทำให้สภาพการจราจรในเขตเมืองมีความหนาแน่นขึ้น ปริมาณการใช้น้ำมันเชื้อเพลิงเพิ่มสูงขึ้น ส่งผลให้คุณภาพอากาศในเขตเทศบาลนคร นครราชสีมา มีแนวโน้มที่จะประสบปัญหามลภาวะอากาศอย่างหลีกเลี่ยงไม่ได้ การศึกษานี้เป็นการตรวจวิเคราะห์หามลสารที่สำคัญได้แก่ คาร์บอนมอนนอกไซด์ (CO), เบนซีน (C_6H_6), ซัลเฟอร์ไดออกไซด์ (SO_2), ไนโตรเจนไดออกไซด์ (NO_2) และฝุ่นละอองที่มีขนาดเล็กกว่า 10 ไมครอน (PM_{10}) ซึ่งแพร่กระจายอยู่ในบรรยากาศในบริเวณที่คาดว่ามีความเสี่ยงสูงในเขตเทศบาลนคร นครราชสีมา โดยเฉพาะในเขตการคมนาคมขนส่งหนาแน่น ผลการศึกษาพบว่าความเข้มข้นของฝุ่นละอองขนาดเล็กกว่า 10 ไมครอน(PM_{10}) ในบรรยากาศสูงกว่าค่ามาตรฐานคุณภาพอากาศของประเทศไทย ในการศึกษานี้ได้ประเมินมลภาวะอากาศที่ปล่อยออกมาจากยานพาหนะชนิดต่างๆ ในปี พ.ศ. 2542 ถึงปี พ.ศ. 2548 ในเขตเทศบาลนคร นครราชสีมา โดยใช้แบบจำลอง มลสารที่ประเมินได้แก่ CO, SO_2, NO_2, HC และ PM_{10} พบว่าสัดส่วนมลสารที่ถูกปล่อยออกมาจากพาหนะชนิดต่างๆ มากที่สุดได้แก่ CO (54.3%) ไฮโดรคาร์บอน (19.0%) และ PM_{10} (17.8%) ตามลำดับ ในการประเมินความเสี่ยงของมลสารต่อสุขภาพของประชาชน พบว่าสารเบนซีน มีความเสี่ยงต่อสุขภาพประชาชนสูงกว่าเป้าหมายที่กำหนด ผู้วิจัยได้เสนอแนวทางการนำเทคโนโลยีและมาตรการต่างๆ ที่อาจช่วยลดปัญหามลภาวะอากาศในเขตเทศบาลนคร นครราชสีมาได้ในอนาคต

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ....ลายมือชื่อนักศึกษา
ปีการศึกษา 2544 ....ลายมือชื่ออาจารย์ที่ปรึกษา

SANGUAN GOSAARAK: AIR POLLUTION ASSESSMENT IN TRANSPORTATION SECTOR IN NAKHON RATCHASIMA MUNICIPALITY THESIS ADVISOR:ASSIST. PROF. RAM SHARMA TIWAREE, Ph.D. 122 PP.

Increasing urbanization and industrial activities, and vehicular traffic have led to an increase in fossil fuels' use and have resulted in a substantial deterioration of air quality in Nakhon Ratchasima municipality. This study analyzed the presence of major pollutants such as carbon monoxide (CO), benzene (C_6H_6), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter (PM_{10}) in the ambient air of selected locations in the Nakhon Ratchasima municipality due to vehicular movements during the dry season of 1999. The study indicates that the concentration of PM_{10} in the ambient air exceeded the existing air quality standard limit of Thailand.

The study has estimated the vehicular emissions of the key pollutants (such as CO, NO_2, SO_2, HC, and PM_{10}) for the year 1999 in Nakhon Ratchasima municipality using a simple model. Among the different pollutants, emission of CO (54.3%) followed by HC (19%) and PM_{10} (17.8%) had largest share in 1999, and thus they were the major pollutants emitted due to the vehicular activities. The study has also estimated the amount of future emission of the above pollutants under business-as-usual scenario for the period 2001 to 2005. The study on risk of air pollutants indicated that the concentration of benzene in the ambient air of Nakhon Ratchasima municipality exceeds the limit of risk goal. Finally, a number of technological options and policy measures are proposed to improve the air quality of the Nakhon Ratchasima municipality in the future.

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ....ลายมือชื่อนักศึกษา

ปีการศึกษา 2544 ....ลายมือชื่ออาจารย์ที่ปรึกษา

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List of Abbreviations

Abbreviation	Description
ACGIH	American Conference of Governmental Industrial Hygienists
A/F	Air to fuel ratio
Avg	Average
BAU	Business as usual
BKK	Bangkok
CDI	Chronic daily intake
C_6H_6	Benzene
CI	Compression Ignition
CO	Carbon monoxide
CO_2	Carbon dioxide
COHb	Carboxyhemoglobin
EF	Emission factors
EGR	Exhaust gas recirculation
HC	Hydrocarbon
HDDV	Heavy duty diesel vehicle
IIP	Indian Institute of Petroleum
LDDT	Light duty diesel truck
LDDV	Light duty diesel vehicle
LDGV	Light duty gasoline vehicle
LPG	Liquified petroleum gas
Max	Maximum
MB	Mini-bus
Min	Minimum
NIOSH	National Institute for Occupational Safety and Health
NKRM	Nakhon Ratchasima municipality
NMHC	Non methane hydrocarbon
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide
OSHA	Occupational Safety and Health Administration
PCD	Pollution Control Department
PM_{10}	Particulate matter less than 10 micron
RON	Relatively Octane Number
SI	Spark Ignition
SO_2	Sulfur dioxide
SPM	Suspended particulate matter
STD	Standard
SUT	Suranaree University of Technology
TERI	Tata Energy Research Institute
UDLE	Urban Development through Local Efforts
US-EPA	United States-Environmental Protection Agency
VOC	Volatile organic compound
WHO	World Health Organization

List of Units

Unit	Description
cm	Centimeter
^{o}C	Degree celsius
d	Day
g	Gram
h	Hour
kg	Kilogram
km	Kilometer
km/h	Kilometer per hour
ktoe	Kilotonne of oil equivalent
kwh	Kilowatt hour
L	Liter
m	Meter
m^3	Cubic meter
mg	Milligram
min	Minute
mm	Millimeter
mmHg	Millimeter mercury
mol	Molecular
mph	Mile per hour
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per thousand
yr	Year
µg	Microgram
1 m^3	= 35.319 ft^3
1013.25 mbar	= 760 mmHg.
1 ppm C_6H_6	= 3.2 mg/m^3 C_6H_6

CHAPTER I

INTRODUCTION

1.1 General

Nakhon Ratchasima city, which lies in the northeastern region of Thailand, has an approximate area of 37.5 km^2 and had a population of about 173,000 in 1999 (Charernwattana, 2000). A map of municipality area is given in Figure A-1 in appendix A. Increased urbanization and industrial activities, and vehicular traffic have led to an increase in the consumption of fossil fuels in this municipality. This is likely to deteriorate the air quality of this municipality. Transport sector is one of the major sectors that consume a large amount of fossil fuel (such as gasoline and diesel) in Thailand as in many developed as well as developing countries. In Thailand, transport sector consumed 18,991 ktoe of petroleum products in 1999 (Department of Energy Development and Promotion, 2000). This was nearly 60% and 68% of the consumption of total fossil fuels and total petroleum products, respectively. In this regard, transport sector has been considered as a major consumer of fossil fuels (i.e., gasoline and diesel) and therefore, a major source of air pollution in Nakhon Ratchasima municipality too.

Many roads in the municipality are fairly narrow where a large number of different types of vehicles are plying everyday. Moreover, Nakhon Ratchasima municipality is a big gateway to other provinces in northeastern Thailand since many vehicles going to those provinces pass through this municipality. In view of this, it is important to assess the air quality, and also to identify the major types of pollutants emitted from transportation and other sectors in this municipality so that effective mitigation programs and policies could be formulated and implemented.

So far, no study for air quality measurement, as well as for the estimation of air pollutants from transportation in Nakhon Ratchasima municipality has been conducted although the Department of Pollution Control, Bangkok has established an air pollution monitoring station in Nakhon Ratchasima as in few other Thai cities including the mega city Bangkok. This study analyzed the air quality at selected locations (road sides) of the Nakhon Ratchasima municipality, and also estimated the existing and future emissions of various exhausts from land transportation including train transport in the municipality.

1.2 Objectives of the Study

The objectives of this study were:

1.2.1 To monitor and analyze the air quality in different parts of Nakhon Ratchasima municipality.

1.2.2 To estimate the existing and future emission of exhaust gases from mobile sources in the municipality and to study the risk of selected air pollutants.

1.2.3 To recommend some appropriate mitigation measures to improve air quality of the municipality.

1.3 Scope and Limitations of the Study

1.3.1 Monitoring of the contaminants, such as CO, SO_2, NO_2, C_6H_6 and PM_{10} in ambient air was done during the dry season (October 1999 to December 1999) in two phases: preliminary survey (6 locations) and in-depth study (2 locations).

1.3.2 Comparison of the above results has been mainly done with the ambient air quality standards of Thailand.

1.3.3 Existing and future emissions of the air pollutants from mobile sources (land transports) in Nakhon Ratchasima municipality area has been estimated using appropriate methods.

1.3.4 On the basis of the limited available information, risk of air pollutant (such as benzene) has been evaluated using a simple model.

CHAPTER II

LITERATURE REVIEW

2.1 General

The sources of air pollution are nearly as numerous as the grains of sand. In fact, grains of sand themselves are pollutants when the wind entrains them and they become air borne. There are basically three different sources of air pollution: natural, anthropogenic and personal sources. Erupting volcanoes, accidental fires in forests, dust storms, oceans, plants tress of the earth are some of the examples of natural air pollution. Industries and utilities are some of the stationary anthropogenic sources of air pollution, while automobiles, energy use in household and commercial sectors, and open burning of refuse and leaves are some of the examples of both stationary an mobile sources of air pollution (Malla, 1993). This study, however, is limited to emission of air pollutants from land transport sector in Nakhon Ratchasima municipality.

Air pollution from motor vehicles in the cities of developing countries does not yet present a problem of the magnitude reached in highly developed countries. However, as urbanization and industrialization develop in these countries, the contribution to air pollution from motor vehicle emissions could increase very rapidly, the more so since the vehicles in service will be on the average older and less well maintained, and have a high weight-to-horsepower ratio; the resulting pollution will be out of proportion to the number of vehicles. The increase in motor vehicles during the last few years in Nakhon Ratchasima municipality has led to adverse consequences public health and the environment.

Environmental concerns of motor vehicles on local, regional, and global scale have brought on many regulations in most emission of the countries. In addition, environmental issues have raised questions about the need for the governments, with possible assistance from the international community, to add yet additional layers of regulation. How these issues are dealt with will influence the future of transportation as well as the economic health of many countries.

2.2 Vehicles and Emission

Motor vehicles contribute significantly to air pollution. The two motor vehicle types responsible for pollutant emission are the vehicles having spark ignition (SI) engines using gasoline as fuel and the others having compression ignition (CI) engines using diesel oil as fuel. Two and three-wheelers are powered by small two-stroke SI engines and are most serious offenders from and air pollution stand point. Passenger cars and jeeps powered by 4-stroke SI engines are less serious offenders of air pollution. CI engines that propel trucks, buses, and of course now cars and jeeps have lower concentrations of pollutant emissions than SI engines, although their exhaust is responsible for higher particulate emissions and has an offensive level (Agrawal, 1991).

The pollutants emitted by motor vehicles are both primary and secondary pollutant types. The principal primary pollutants include CO, unburnt HCs, NO_x, SO_2, particulate matter, including lead compounds, and noise. The secondary pollutants include the photochemical smog. The principal emissions from gasoline vehicles are CO, unburnt HCs, NO_x, and particulates, including lead compounds. On the other hand, diesel vehicles contribute largely NO_x and particulates (diesel smoke) to the atmosphere. Diesel vehicle also emit CO and unburnt HCs, but their contribution to these pollutants per liter of fuel consumed is relatively low compared to that for gasoline vehicles. The degree of contribution to air pollution depends on population, traffic flow and particularly the type of fuel, its impurities and additives, and the combustion conditions.

2.2.1 Environmental Effects of Air Pollutants

The pollutants emitted by motor vehicles cause or contribute to adverse health effects on many individuals; in addition to harming terrestrial and aquatic ecosystems, causing crop damage and impairing visibility. Additionally, HCs and NO_x emissions undergo photochemical reactions and generate several secondary pollutants e.g., peroxy benzyl and acyl nitrates, aldehydes etc. which are very strong eye, nose and throat irritants; Ozone produced has an adverse effects on rubber compounds, and other similar compounds. Evidence exists that SO_2 and particulate matter (PM) also contribute to smog formation. CO_2 does not contribute to visible smog, though it is believed to have some effect on the temperature of earth through greenhouse effect (Indian Institute of Petroleum, 1985).

Table 2-1 summarizes the adverse effects of the pollutants emanating from vehicles which are of principal concern (Noel, 1995). The pollutants emitted by different types of vehicles and their effect on the environment as indicated by symbol X are summarized as shown below.

Table 2-1. Major air pollutants and their effects.

Pollutant	Main effects
CO_2	Change in the global atmosphere
CO	Poisonous even in very small concentration
NO_x	Reduce resistance to disease, change in global warming
SO_2	Acid rain; damage to trees, crops and buildings
HCs	Health and ecological hazards
Lead	Damage to brain and nervous system, especially to children
Dust	Bronchitis and other diseases

Source: Noel (1995).

Vehicles	Pollutants	Toxic	Smog	Visibility
2 & 3 wheelers	Lead	X	-	X
	CO	X	-	-
Cars/jeeps	HC	-	X	X
	NO_x	X	X	X
Trucks/buses/	Smoke	X	-	X
Mini-buses	Odor	X	-	-
	SO_2	X	-	-

2.2.2 Vehicle Types

The following 3 main types of vehicles are used in Thailand and also in Nakhon Ratchasima province.

1. Passenger cars and jeeps powered by 4-stroke gasoline (SI) engines.
2. Two wheelers powered mostly by small 2-stroke gasoline (SI) engines.
3. Three wheelers powered mostly by small 2-stroke liquified petroleum gas (LPG) engines.
4. Buses, trucks, and light diesel commercial vehicles powered by 4-stroke diesel (CI) engines.

For the past few years, cars and jeeps powered by diesel engines are also running. Some of three wheelers are also run on LPG. The above mentioned categories essentially represent the entire vehicle population. In addition, diesel tractors and power trailers are used mostly in the rural areas.

2.2.3 Sources of Pollution from Vehicles

The sources of air pollution from vehicles are shown in Figure 2-1. There are the following three sources of emissions.

Crankcase Blowby

During compression and expansion phases of the SI engine operation, the pressure of the gas inside the cylinder is very high and therefore they leak past the piston and piston rings into the crankcase to be discharged to the atmosphere through draught tube and other vents which is known as "blowby". Any blowby that is discharged into the atmosphere is rich in unburnt HCs and contain small amount of CO. The crankcase blowby is responsible for approximately 20% of the particulates emitted by the vehicles. Particulates in blowby gases consist almost entirely of lubricating oil. On the other hand, the blowby gases from the CI engines which use diesel oil, consist primarily of air, and HCs emissions from the crankcase are rather low.

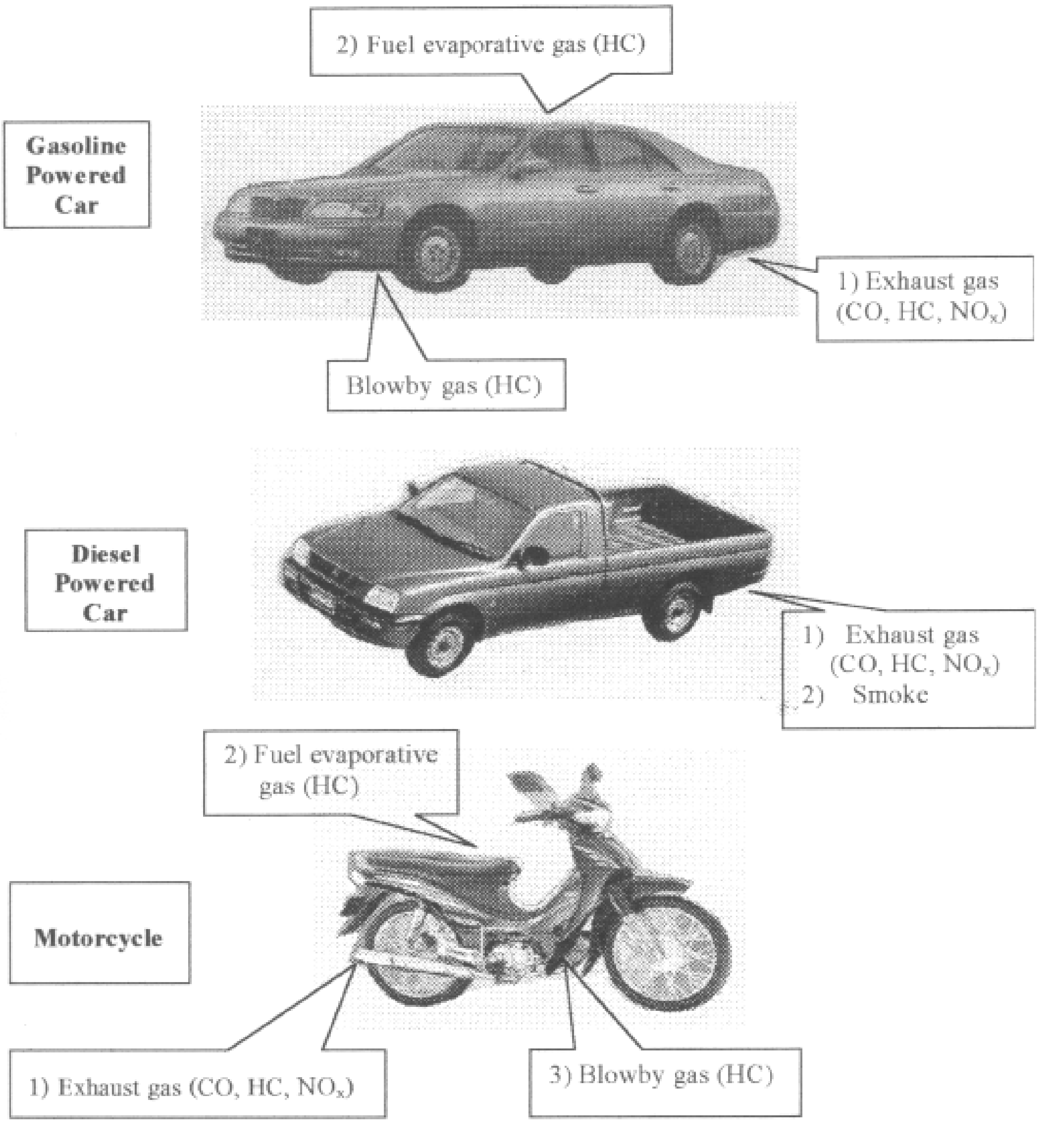

Figure 2-1. Sources of air pollution from vehicles.

Evaporative Emissions

The evaporative emissions occur via (a) the fuel tank, and (b) the carburetor. Gasoline is highly volatile substance and so it evaporates very easily. The volatility of diesel oil is in general, low. Thus, the consequent evaporation losses are also lower. The evaporative rate increases with ambient air temperature. When the vehicle is parked in open areas under sunshine, the evaporation of the fuel accelerates, so the loss of fuel and consequently air pollution is even higher.

Evaporative losses from fuel tank consist primarily of the more volatile fractions of the fuel displaced from the tank. Evaporative losses also occur from the carburetor. An appreciable quantity of fuel is evaporated from the carburetor and escape through carburetor vents and openings. Automobile fuel evaporating from the tank and carburetor through overflow and venting channels account for 20% of the total HC emission. They become even more during the summer.

Exhaust Emission

Exhaust emission from a gasoline powered engine consists mainly of CO, unburned HCs, NO_x, and partial oxidation products of the aldehydes family. In addition particulate matter in the form of lead compounds and carbonaceous matter are also emitted. On the other hand, exhaust emissions from diesel powered vehicles have low CO and unburnt HCs, while NO_x is present in high concentration. Besides, these emissions contain smoke particles, oxygenated HCs, including aldehydes and odor roducing compounds.

2.2.4 Pollutant Formation Mechanisms

The process responsible for the formation of major pollutants in the cylinder of the SI engine is that the combustion process is initiated by a spark and the frame formed then travels outward in all directions through the air/fuel mixture towards the walls of the combustion chamber. These walls are metal surfaces which are cooled from outside to prevent damage due to high temperatures. As the frame approaches the relatively low temperature metal surfaces, it gets quenched leaving a thin layer of unburnt mixture, typically a few thousandth's of centimeter thick.

The diesel vehicles are CI engines. When the piston descends, air is induced in the cylinder and when the piston ascends then air which is initially at the atmospheric pressure is compressed raising its temperature to 600 ^{o}C. At this point, a high pressure injector injects the fuel which is heated up by the crankshaft revolution and the fuel undergoes spontaneous ignition. The ratio of mass of air to mass of fuel is always high and thus there is always sufficient oxygen to ensure complete combustion of fuel to CO_2 and water, obviously very little CO is formed. Some of the major outdoor air pollutants are described in the next subsection (Malla, 1993).

2.3 Major Outdoor Air Contaminants

2.3.1 Carbon Monoxide (CO)

Characterization

Carbon monoxide (CO) is a colorless, odorless, tasteless, and flammable gas, slightly lighter than air and slightly soluble in water. It is very stable and has a lifetime of two to four months in the atmosphere. Soil fungi may remove a significant amount of CO to CO_2 into the atmosphere, although the rate is quite slow (Nieh, 1992).

Carbon monoxide enters the body through the respiratory system and reacts primarily with the hemoglobin of the blood. The combination of carbon monoxide with hemoglobin leads to carboxyhemoglobin (COHb). Because the quantity of COHb in the blood is a function of the concentration of CO in the air breathed, we often use saturation (%) of COHb as an indicator of CO uptake. When exposure to high levels of atmospheric CO, the percentage of COHb will increase. When exposure is discontinued, CO combined with the hemoglobin is spontaneously released and the blood is cleared of half its carbon monoxide in healthy subjects in three to four hours (Nieh, 1992).

Sources

Natural sources come from atmospheric oxidation of methane and other biogenic hydrocarbons. All of these are manmade pollution. Anthropogenic source is from combustion of fossil fuels. Carbon monoxide is a primary pollutant produced by incomplete combustion of fuel. Due to improper mixing of air and fuel, insufficient oxygen is present during combustion, so that the fuel is not completely oxidized. Automobiles have a relatively high concentration of CO in the exhaust, because the ignition and combustion of the vaporized air-fuel mixture are rapid and non uniform and the combustion conditions are poorly controlled.

Thus carbon monoxide is an intermediate product of the automobile gasoline consumption. Its depends primarily upon the air to fuel (A/F) ratio. If there is not enough air in the A/F mixture to completely burn the fuel, or if there is insufficient time in the cycle for complete combustion, all the carbon in the fuel can not be burned to CO_2 and some of it stops midway to form CO. Even if enough air is present the rapid cooling of gases during expansion allows the combustion process to retain a small amount of CO in the exhaust gases.

Health Effect

Carboxyhemoglobin reduces oxygen delivery to tissues. Tissues with the highest oxygen needs, myocardium, brain and exercising muscle, are most affected by the formation of carboxyhemoglobin.

Table 2-2. Health effects of carboxyhemoglobin concentration.

COHb (%)	Effects
0.4	Normal physiologic value for nonsmokers
2.5 to 3.0	Decreased exercise performance in patients with angina or with intermittent claudication
4.0 to 5.0	Increased symptoms in traffic policemen (headache, lassitude); increased oxygen debt in non smokers
5.0 to 10	Cardiac and pulmonary functional changes; diminution of visual perception, manual dexterity, or ability to learn
more than 10	Headaches, fatigue, drowsiness, coma, respiratory failure, death

Source: Nieh (1992).

2.3.2 Nitrogen Oxide (NO_x)

Characterization

Nitric oxide (NO) and nitrogen dioxide (NO_2) are the two most important nitrogen oxides air pollutants. They are both formed as products of combustion, frequently lumped together under the designation of NO_x.

NO is a colorless, odorless gas, non-flammable slightly soluble in water and toxic. Its global background level ranges from 10 to 100 ppt. NO_2 is a reddish-orange-brown gas with sharp and pungent odor, toxic and highly corrosive, absorbs light over much of the visible spectrum. Nitrogen dioxide is the more reactive and poses the greater health hazard. The earliest response to NO_2 occurs in the sense organs.

As the nitric oxide is converted to nitrogen dioxide it creates a problem in polluted air. Nitrogen dioxide is a strong absorber of ultraviolet light from the sun and triggers photochemical reactions that produce smog that irritate the eyes (Nieh, 1992).

Sources

The major source of oxides of nitrogen in the atmosphere is the biological degradation of nitrogen compounds in the soil. Man-made emissions are due to combustion of fuels from burning coal, oil or gas and from vehicle emissions of diesel and petrol engines and aircraft. The highest concentration occurred when the junction have traffic lights and the main duel carriage way traffic flow is interrupted from time to time. The motor vehicle is the major contributor of NO_2 in this area. NO_x are formed in the combustion chamber where the temperature is as high as 2500 °C within the frame which is caused by an ignition at the spark plug in the spark ignition engine.

This high temperature makes oxygen and nitrogen combine. The mechanism of nitric oxide formation in CI engines is rather complex and of the major contributors may be the lean flammable region. Nitric oxide formation in CI engine is also influenced by combustion pressure, temperature and the time available for combustion. Therefore, nitric oxide emissions tend to increase with advanced injection timings, increase in compression ratio and turbo-charging. A higher octane number of fuel has observed to result in lower nitric oxide emissions. Another major source of NO_x is the chemical industry, fertilizer and nitric acid manufacturing companies.

Nitric oxide and nitrogen dioxide are the principal by products of combustion processes. Such high temperature can be observed in the frames of gas and kerosene combustion appliances. The oxidation of N_2 by the O_2 in combustion air occurs primarily through the two reactions:

$$N_2 + O \rightarrow NO + N$$
$$N + O_2 \rightarrow NO + O$$

The first reaction has a relatively high activation energy due to the need to break the strong N_2 bond. Because of the high activation energy, the first reaction is the rate-limiting step for NO production, proceeds at a somewhat slower rate than the combustion of the fuel and is highly temperature-sensitive.

The second major mechanism for NO formation in combustion is by the oxidation of organically bound nitrogen in the fuel. A portion of fuel is converted to NO_x during combustion, the remainder is generally converted to N_2. Although NO is the dominant NO_x compound emitted by most sources, NO_2 fractions from sources do vary somewhat with source type. Once emitted, NO can be oxidized quite effectively to NO_2 in the atmosphere through atmosphere reactions (Nieh, 1992).

Health Effects

Work done in America using control groups has suggested that levels as low as 200 $\mu g/m^3$ increase the incidence of acute respiratory illness (Nieh, 1992). Concentrations as low as five parts per million (ppm) can cause respiratory distress; approximately 50 ppm can cause chronic lung disease and above 150 ppm is lethal (William et al, 1992).

2.3.3 Suspended Particulate Matter (SPM)

Characterization

Suspended particulate matter is generally considered to consist of all airborne solid and low-vapor-pressure liquid particles less than a few hundred micrometers in diameter.

Atmospheric air is contaminated by a variety of particles such as soot, ash, pollens, mould spores, fibrous materials, dust, grit, and disintegrated rubber from roads, metallic dusts, and bacteria. The heavier particles under calm conditions they will settle down by their own volition. The smokes, gases and lighter particulate matters remain suspended in the atmosphere until removed by rain and wind.

Dust is solid particles produced by natural or man-made processes of erosion, crushing or other abrasive wear. Dust does not agglomerate, except under the influence of electrostatic forces, but settle on the ground by the force of gravity.

Fumes, with a diameter less than 1 μm, also are solid particles but forms in a different way from dusts. Fumes are produced by sublimation, or by the condensation and subsequent fusion. Under normal temperature and pressure, the particles in gases are solids.

Health Effects

Normal air contains dust, but this is quickly removed once it has reached deeper structures of the lung. The sticky mucus on the nasal mucosae hold coarser dust particles thus preventing them from entering the remoter respiratory passages. The trachea and bronchial tubes are also coated with mucus reinforcing the cleaning effect. However, finest dust particles will reach the deepest structures of the lung. This would become a threat to life. The very fine particles are therefore ingested by wandering cells and taken to the lymph glands that are at the root of the lungs. There, the dust is deposited. The glands are always found to be black from deposited dust.

Asbestos fibers have been associated with chronic lung disease and with lung cancer. The fibers are given off by the brake linings of automobiles, roofing materials and shingles. Lead is a cumulative poison taken into the body in food and water as well as air. Most lead in the atmosphere is the result of leaded gasoline in automobiles. Lead appears to interfere with brain function rather than to damage the cells themselves (Clark, 1981).

Bacteria are generally larger in size than 1.0 μm and rely on dust particles as a mode of transport. Hence, dust filtration is important in controlling the spread of infection by bacteria. Viruses are very small, some are transported by airborne liquid droplets (Jones, 1973).

2.3.4 Benzene (C_6H_6)

Characterization

Benzene, a widely used chemical with an annual production of about 10 billion pounds is a small compound (mol wt 78.11); it is a clear, colorless, highly flammable liquid that is soluble in 1430 parts of water and also is miscible with alcohol, chloroform, ether, carbon disulfide, carbon tetrachloride, glacial acetic acid, acetone, and oils. Because of its low boiling point (80 °C), benzene exists both as liquid and vapor, the industrial worker and the public are exposed to both forms.

Source

Burning of fossil fuel generate hydrocarbon including C_6H_6. In case of vehicles. With SI engines the principal mechanism of its formation has been attributed to the destruction of flame propagation radicals due to quenching in the engine combustion chamber. High HC emissions can also result from either too lean or too rich local mixture in the engine.

There are two major sources which contribute to unburned HCs in CI engines: (a) fuel premixed to linear than the lean limit conditions remaining unburned, and (b) emptying of fuel from the nozzle sac and hole volume, resulting in local fuel rich conditions as the diesel fuel issues slowly from the nozzle.

Health Effects

Human toxicity manifests itself as irritation of mucous membranes, restlessness, convulsions, excitement, and depression, chronic exposure causes bone marrow depression and a plastic leukemia. Perry and Gee (1993) reported that benzene in vehicle emission has been established as carcinogenic or mutagenic. Long term exposure to benzene is implicated in increased leukemia.

Concerns about the toxicity and carcinogenicity of benzene have led to continuing pressure to lower the levels of allowable occupational exposures and have raised the issue of possible health risks to the general population from atmospheric benzene pollution. If realistic decisions about minimizing risk are to be made as allowable levels become even lower, questions about the relative importance of various routes of exposure and the role of distribution and metabolism must be reconsidered.

2.3.5 Sulfur Dioxide (SO_2)

Characterization

The oxidation of sulfur dioxide leads to the production of sulfuric acid, which contributes to acid precipitation. Its atmospheric lifetime which respect to oxidation is typically a few days. However, the rate of oxidation is variable, since it may occur both in aqueous droplets (e.g., clouds) and in the gaseous phase where the sulfuric acid itself may condense to form condensation nuclei.

Sources

Man-made sulfur dioxide results mainly from fossil fuel combustion, power plants, transports, chemicals, iron, and steel industries etc. From the vehicles it is formed on the SI and CI engines due to oxidation of sulfur during the combustion process. The quantity of sulfur compounds present in the gasoline depends on the source of crude oil and to some extent on the method used in the refining of oil. The diesel oil has a higher sulfur content which could be as high as twenty time that in gasoline. The oxidation on sulfur produces SO_2.

Health Effects

The major health concerns associated with exposure to high concentrations of SO_2 include effects on breathing, respiratory illness, alterations in pulmonary defenses, and aggravation on existing cardiovascular disease. Children, the elderly, and people with asthma, cardiovascular disease or chronic lung disease such as bronchitis or emphysema.

2.4 Air Pollution Meteorology

When a gaseous or particulate emission, be in from a vehicle exhaust or other sources, is released into the atmosphere its fate is almost impossible to predict. This is so because of the complex factors that influence its subsequent pathways. The influencing factors are primarily:

- Meteorological
- Source
- Process

The meteorological factors of interest are:
- Wind speed and direction
- Temperature and humidity
- Turbulence
- Atmospheric stability
- Topographic effects on meteorology

Air pollution emissions are of interest at three scales:
- Microscale - of the order of 1 km (e.g. chimney plumes)
- Mesoscale - of the order of 100 km (e.g. mountain-valley winds)
- Macroscale - ~ thousands of km (e.g. highs/lows over oceans)

These scales are also time related and since wind speeds are ~5.0 m/s, the microscale meteorological effects occur at duration of minutes to hours, the mesoscale from hours to days and the macroscale at days to weeks (Kiely, 1997).

2.5 Ambient Air Pollution Estimation

Pollution Control Department (PCD) in Bangkok has established air pollution monitoring stations in different cities, including Nakhon Ratchasima, Khonkaen, Saraburi, Chaing Mai, Cholburi, and Hat Yai etc. The objective of these stations is to make 24-hour forecast of air pollution situation in order to warn the public and employ mitigation measures to decrease the level of pollutants to a safe limit for public health.

Mitigation measures generally used are:

1. reduction of the emission of pollutants at sources,
2. warning to publics through the public media,
3. awareness campaign for mitigation measures, and
4. warning the people to be ware of their health, especially children, elderly, and people with asthma etc.

These air pollution stations monitor the followings:

(i) Air pollution parameters:

CO, SO_2, NO_2, and PM_{10} etc.

(ii) Meteorological parameters:

Wind speed, wind direction, temperature, relative humidity, net radiation air pressure and rain.

Finally, these air quality forecasting and warning stations employ the following tools:

1. Regression model has been used to make a 24-hour forecast of PM_{10}, SO_2, NO_2, and CO levels in Bangkok and other major cities.

2. Grid model, which is an air quality dispersion model has been used to determine control measures required for emission sources as part of the warning system operation.

Collection and data analysis of pollutants and other parameters is done by the Collection and Analyze Data Section (CADS) of PCD. CADS is the computer system which has AIRVIRO software. This AIRVIRO software can search the data or database in meteorology, emission sources, and mathematical model for air pollution dispersion evaluation. The present air quality forecasting and warning system is a reasonable predictive tool that has been used by PCD staff for daily prediction using the minimum necessary amount of data and efforts (Pollution Control Department, 1999). Such models are not available for private use.

2.6 Number of Vehicles in Nakhon Ratchasima Province (Muang District)

Types of the vehicles registered in Nakhon Ratchasima province (especially Muang district) in 1999 under Motor Car Act 1979 are: sedans = 22,114, vans and pick-ups = 57,150, 3-wheelers = 989, motorcycles = 178,463. The number of vehicles under Land Transport Act 1979 are: fixed route buses = 2,141, non fixed route buses = 165, private buses = 107, private trucks = 7,601. Tables A-1, A-2 (appendix A) show the number of various types of vehicles in Nakhon Ratchasima province (Muang district).

2.7 Factors Affecting Vehicular Emission

Several factors affect the emission of exhausts from different types of vehicles. Therefore, it is necessary to explain about such factors before presenting any model for the estimation of any exhaust from transports. These are briefly given below.

2.7.1 Effect of Driving Mode

The composition and quantities of emission products from vehicles depend on the mode of driving. When the engine started from the cold, as the fuel vaporization is slow, the fuel flow is increased with a choke to provide an easily combusible fuel rich mixture near the spark plug. Thus, until the engine warms up and the choke is released, CO and HC concentrations in the exhaust are high because the mixture is made fuel rich for smooth running, but nitric oxide is low because of low temperature level and oxygen scarcity. When the vehicle cruises at high speed, HC and CO emissions are very low because the mixture is set at slightly fuel-lean for best economy. Deceleration results in very high concentrations of HCs and CO in the exhaust.

2.7.2 Effect of Type

The type of vehicle and traffic density affects the atmospheric pollution in any city. Gasoline vehicles emit maximum amount of air pollutants in comparison to those with diesel. Among the gasoline vehicles, two stroke-SI engines give out maximum HCs, while four stroke-SI engines emit maximum amount of NO_x and CO. The two stroke gasoline engines which are used in two and three wheelers release about 30 to 100 times larger amount of unburnt HCs and more of CO than the four stroke or diesel engines.

2.7.3 Effect of Urbanization and Density of Vehicles

As an urban area grows, so does the number of vehicles, which in turn means more pollution. Narrow roads which were designed in pre-automobile age, congestion, formation of long queues at intersections and quite low speed, particularly near residential and shopping area aggravate the situation in the city. Air quality in the urban areas is not only a reflection of the escalating number of vehicles, but also of the changing urban landscape. The change in the urban landscape will have inadvertently alter the wind field and the dispersion of air pollutants.

2.7.4 Effect of Fuel Properties on Emissions

Gasoline Fuel

Increase involuntarily caused some increase in HC and NO_x emissions under driving cycle test. Increase in viscosity has been observed to decrease CO emissions at idling, but gives caused change in NO_x emissions and there is variable effect on HC emissions. As regards the relationship between HC emissions and specific gravity, there are contradictory results. CO emissions are not influenced by the specific gravity of the fuel. Poly Aromatic Hydrocarbon emissions are very much sensitive to fuel aromatic and are directly proportional to the aromatic content of the fuel, but aldehyde emissions fall as the aromatic content of the fuel is increased.

Diesel Fuel

Compared to the influence of engine design and operating conditions, the properties of diesel fuels have very little influence on the emission of pollutants. Two fuel characteristics mainly responsible for particulate emissions are: aromatic content and volatility of diesel fuel. Contradictory results with regard to the influence of cetane number on particulate emissions have been reported by different researchers. SO_2 emissions from diesel engine are directly proportional to the fuel sulfur content.

The effect of variation in fuel properties on the exhaust emissions of HC, NO_x, CO, and smoke is generally small in practical terms. The nature of influence also depends upon the engine design. It may be concluded that the effect of fuel properties on exhaust emissions of HC, CO, and NO_x is rather low and very often, contradictory results have been obtained (Malla, 1993).

2.8 Emission Factors

An emission factor (EF) is defined as the ratio of the rate at which a pollutant is released into the atmosphere as a result of some activity, such as, domestic fuel combustion or industrial production to the rate of that activity. The emission factors can be determined by detailed source testing involving many measurements or by engineering analysis of process material balances. The unit of emission factors for mobile source is expressed in g/km.

United States -Environmental Protection Agency (US-EPA) Emission Factors

Many factors, which vary with geographic location and estimation situation, can affect emission estimates considerably. The factors of concern include: average speed, percentage of vehicle kilometer traveled in cold/hot start vehicle operation, percentage of travel by vehicle type, level of fuel volatility, air conditioning usage, humidity etc. Clearly, the innumerable combinations make it impossible to present vehicle emission factors for each application. US-EPA has developed emission factors expressed in g/km on the basis of the following assumptions:

1. The different vehicle fleets were assumed as follow:
   Heavy duty diesel vehicle (HDDV) - trucks and buses
   Light duty diesel truck (LDDT) - minibus and tractors
   Light duty diesel vehicle (LDDV) - jeeps
   Light duty gasoline vehicle (LDGV) - cars
2. The average speed considered was 31.4 km/h (19.6 mph) and the calendar year 1980 was assumed for exhaust emission factors on the basis of average age of the different vehicles that were surveyed.
3. The ambient temperatures considered were 9.7 °C (75 °F) for winter and 23.5 °C (100 °F) for summer and the operating mode combination was 20.6% cold start, 52.1% stabilized, and 27.3% hot start.

Table 2-3. US-EPA (1973) emission factors in g/km.

Pollutants	LDGV	LDDV	HDDV	2 / 3-Wheelers
Particulate	0.21	0.45	0.75	0.21
SO_2	0.08	0.39	1.5	0.024
Aldehydes	-	-	0.2	0.068
Organic acid	-	-	0.2	-

Source: United States-Environmental Protection Agency (1973).

The emission factors prepared by the US-EPA on the basis of above assumptions are given in Tables 2-3 and 2.4.

Table 2-4. US-EPA (1991) emission factors in g/km.

Pollutants	HDDV	LDDT	LDDV	LDGV	
	0-100 °F	0-100 °F	0-100 °F	75 °F	100 °F
Exhaust NMHC	6.09	1.26	0.74	3.23	3.68
Exhaust CO	15.48	2.25	1.53	50.4	80.0
Exhaust NO_x	18.07	1.2	0.94	1.36	1.02

Source: United States-Environmental Protection Agency (1991).

European Emission Factors

It is important to note that emissions factors may differ from one country to another, which does not mean that one factor is right and another one wrong. The aim of comparing emission factors is much more to learn about information available in different countries, and to understand the reasons for existing differences. Table 2-5 shows the emission factors for motor vehicles under urban driving conditions in Europe.

Table 2-5. European emission factors in g/km.

Pollutants	Truck	Bus	MB	Jeep	Car	3-wheelers	2-wheelers
CO	10	14	4	3.5	17	20	5
VOC	7	10	2	1.1	3.2	2	4
NO_x	10	15	6	1.2	1.58	0.2	0.05
Particulate	3.5	5	1.5	1.0	0.06	0.05	0.06

Source: Lubkert et al (1989).

Indian Institute of Petroleum (IIP) Emission Factors

The driving cycle adopted by IIP for measuring the emission factors is termed as four-mode cycle and consists of four modes of operations-idling, acceleration, running, and deceleration. Table 2-6 is compiled to provide basic data for estimation of emissions.

Table 2-6. Emission factors for different vehicles (g/km).

vehicle	CO	HC	NO_x	SO_2	Pb	TSP
Two-wheeler	8.30	5.18	-	0.01	0.00	-
Cars	24.03	3.57	1.57	0.05	0.01	-
Three-wheelers	12.25	7.65	-	0.03	0.01	-
Buses (urban)	4.51	1.75	8.52	1.48	-	0.28
Trucks	3.52	1.36	6.66	1.16	-	0.22
Light commercial vehicle	1.30	0.50	2.50	0.40	-	0.10

Source: Tata Energy Research Institute (1992).

Following assumptions were made to estimate the emission factors of SO_2 in the Table 2-6. In gasoline, the concentration of sulfur ranges from 0.05 to 0.1% (wt/wt). For the calculation of SO_2 emissions, an average sulfur concentration in gasoline of 0.08% has been taken. Further, it was assumed that all the sulfur get converted to SO_2 and was exhausted through the tail pipe. For diesel fuel, the concentration of sulfur was approximately 0.75% (wt/wt) and all the sulfur present in diesel fuel gets converted into SO_2.

2.9 Research on Air Pollution from Road Transport

Walsh (1990) concluded that HC, CO, and NO_x emissions from motor vehicles are major sources of climatic modification as well as adverse health and other environment effects from ground level pollution. Emission of these pollutants depends on the number of vehicles in use and their emission factors. The actual emission factors depend on their fuel efficiency and their use of available control technologies such as catalytic converters. The author suggested some of the policies to address air pollution and global warming.

Ang (1991) highlighted the effects of the four operational changes on the fuel consumption of scheduled buses. They are: a change in the brand of engine oil used, a switch from cross-ply to radial tires, engine overhaul, and vehicle maintenance. The author did not mention the effects on environmental pollution.

Estimates of transport related urban air pollution are based on traffic flow characteristics, vehicle numbers, vehicle types, and total km of travel. Exhaust emissions of NO_x, HC, and CO are dependent on traffic flow characteristics which are normally measured by a driving cycle. Lyons et al (1990) suggested that urban structure and air pollution can be linked directly through the way that vehicles are driven in different types of traffic resulting from variations in land use patterns. However, this does not mean that simple dispersal of land uses away from city centers will lower emissions, as it denies the complex relationship between transport and land use. It appears that the upgrading of public transport to city centers will have a more significant contribution to urban air pollution.

Malla (1993) estimated the air pollution from energy use in Kathmandu. He found that road transport was the main source of air pollutants with largest share by carbon monoxide. He estimated the pollutants quantity from road transport based on estimated number of vehicle types, their mode of operation, and appropriate emission factors etc.

According to Dupont (1989), emission factors of pollutants from different appliances can vary over several orders of magnitude. This variation is due to the fact that pollutant emissions from combustion processes depend on many interrelated factors type of fuel, type of appliances, appliance tuning and maintenance, degree of venting, age, combustion efficiency, and amount of use.

2.10 WHO guidelines for non-conventional pollutants

The World Health Organization (WHO) (1996) has issued a document which includes guidelines for non-conventional pollutants. The American Conference of Governmental Industrial Hygienist (ACGIH) (1996) guidelines includes information based on health and other effects which should be considered in setting ambient air quality standards. Table 2-7 illustrates the standard and guidelines of benzene for working place and ambient air level, and the time-weighted average (TWA) concentration for a conventional 8-hour workday.

Table 2-7. Summary of standard and guidelines for benzene.

Substance	For working place		For ambient air level		
	NIOSH	OSHA	WHO	US-EPA	ACGIH
Benzene	3 mg/m^3 avg. 8 h.	30 mg/m^3 avg. 8 h.	No safe level	53.4 $\mu g/m^3$ avg. 8 h.	10 ppm (32 mg/m^3) TWA

2.11 Risk Assessment

Risk assessment can be divided into the following four steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization (Masters, 1990). After a risk assessment has been completed, the important stage of risk management follows, as shown in Figure 2-2.

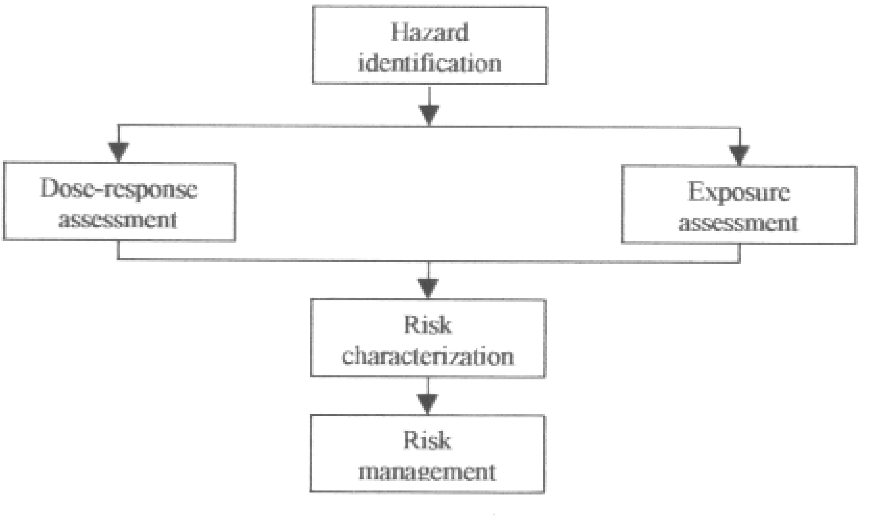

Figure 2-2. Four-step process of risk assessment.

The term "risk assessment" has different meanings to different groups, such as scientific, political, financial, and security (Asian Development Bank, 1991). For scientific groups, risk assessment may be defined as the scientific evaluation of known or potential adverse health effects resulting from human exposure to environmental pollution hazards, such as airborne hazards or waterborne hazards (United States National Research Council, 1983).

- ***Hazard Identification*** is the process of determining whether or not a particular chemical is causally linked to particular health effects, such as cancer or birth effects. Since human data are so often difficult to obtain, this step usually focuses on whether a chemical is toxic in animals or other test organisms. However, animal testing method has certain shortcomings. Sometimes human data can be obtained from victims of the tragedies, such as the chemical plant explosion that killed and injured thousands in Bhopal, India, and atomic bombing of Hiroshima and Nagasaki, Japan. Most important source of human risk information, however, comes from epidemiologic studies. Epidemiology is the study of the incidence rate of diseases in real populations.

- ***Dose-response Assessment*** is the process of characterizing the relationship between the dose of an agent administered or received and the incidence of an adverse health effect. Many different dose-response relationships are possible for any given agent depending on such conditions as whether the response is carcinogenic (cancer causing) or non-carcinogenic and whether the experiment is a one-time acute test or a long-term chronic test. Since most tests are performed with high doses, the dose-response assessment must include a consideration for the proper method of extrapolating data to low exposure rates that humans are likely to experience.

- ***Exposure Assessment*** involves determining the size and nature of the population that has been exposed to the toxicant under consideration, and the length of time and toxicant concentration to which they have been exposed. Consideration must be given to such factors as the age and health of the exposed population, smoking history, the likelihood that member of the population might be pregnant, and whether or not synergistic effects might occur due exposure to multiple toxicants.

- ***Risk Characterization*** is the integration of the foregoing three steps, which results in an estimate of the magnitude of the public-health problem. The final step in a risk assessment is to bring the various studies together into an overall risk characterization. In its most primitive sense, this step could be interpreted to mean simply multiplying the exposure (dose) by the potency to get individual risk, and multiplying that by the number of people exposed to get an estimate of overall risk to some specific population.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Ambient air Sampling and Analysis

3.1.1 Identification and Selection of Study Locations

Air sampling locations were identified near the roads having daily high traffic congestion, narrow roads, tall buildings, large movement of people. Six locations were selected for preliminary ambient air quality evaluation, i.e., the measurement of concentration of pollutants, such as CO, SO_2, NO_2, C_6H_6, and PM_{10} in the ambient air.

The selected six locations for preliminary survey are shown in Table 3-1 along with sampling date and time.

Table 3-1. Sampling location and experiment date.

Station	Sampling location	Experiment date	Schedule of daily sample collection
A1	Ratchadamnern Rd. near Thao Suranaree monument.	8 Nov 99	1. 06:30 – 07:30 am. 2. 08:00 – 09:00 am. 3. 12:00 – 01:00 pm. 4. 02:30 – 03:30 pm. 5. 04:00 – 05:00 pm. 6. 06:00 – 07:00 pm.
A2	Phoklang Rd. in front of Nakhon Ratchasima provincial electricity authority office.	11 Nov 99	
A3	Mitraphap Rd. in front of Nakhon Ratchasima vocational college.	12 Nov 99	
A4	Mitraphap Rd. in front of Nakhon Ratchasima bus terminal No.2.	13 Nov 99	
A5	Ratchasima-Chokchai Rd. at intersection to go to Chakarat district.	15 Nov 99	
A6	Chomphon Rd. at the Night bazaar commercial market area.	16 Nov 99	

The experiment dates for in-depth investigation were:

a) Station one Ratchasima-Chokchai road from 25 November to 1 December 1999, time 06:30 am. to 07:00 pm.

b) Station two Chomphon road near night bazaar from 2 to 8 December 1999, time 06:30 am. to 07:00 pm.

Based on the information obtained from preliminary analysis of pollutants in ambient air, such as, high concentration of pollutants in the ambient air, heavy traffic, narrow road, high business activity etc., two locations were selected for in-depth study. Those two locations were: (i) Ratchasima-chokchai road and (ii) Chomphon road near night bazaar.

3.1.2 Samples Collection and Analyses

a) Preliminary survey: As mentioned in Table 3-1, six one hourly ambient air samples for each of the CO and C_6H_6 and one 12-hourly ambient air samples for each of SO_2, NO_2, and PM_{10} were taken during the period 8 to 16 November, 1999. All samples were analyzed using appropriate apparatus and average maximum, minimum, and mean values concentration of each pollutant were determined.

b) In-depth study: Two locations were selected for in-depth study. Ambient air sampling of different pollutants were done during the period 25 November to 1 December 1999 (from 6:30 am. to 7:00 pm.) and 2 to 8 December 1999 (from 6:30 am. to 7:00 pm.) at station I (Ratchasima-Chokchai road) and station II (Chomphon road near night bazaar), respectively. A total of forty-two one-hourly ambient air samples for each of the pollutants, such as, CO, and C_6H_6 (six samples per day per station for a week), six 12-hourly ambient air samples (one sample per day per location for 6 days), and one 24-hourly ambient air samples for each of the SO_2, NO_2, and PM_{10} in each of the above two locations were taken. These samples were analyzed, and average maximum, average minimum and mean concentration values for each pollutant at each location were determined.

3.1.3 Sampling Equipment and Instruments

The following instruments were used to collect and analyze ambient air samples for different pollutants: (i) Portable ambient air analyzer, Foxboro type, model: MIRAN 1 BX for CO, and C_6H_6, (ii) High volume air sampler, Anderson for PM_{10}, (iii) Sampling train analyzer, Paragon model 7007-00 (for the sampling of SO_2 and NO_2) and (iv) Spectrophotometer BACHARACH Coleman model 35 (for the analysis of SO_2 and NO_2). A short description of the above instruments is mentioned below.

(a) ***Portable Ambient Air Analyzer***

MIRAN 1 BX is one of the gas analyzers suitable for field inspection. It can monitor inorganic and organic gases according to the Occupational Safety and Health Administration of U.S.A. (OSHA) method (The Foxboro Company, 1989). It has basic program for monitoring more than 100 kinds of gases. The system uses infrared spectrophotometer single ray type with microprocessor, automatic control which can analyze or compute the value of absorbance in ppm unit. Figure 3-1 shows the structure of this type of analyzer which was used for sampling/analyzing of CO and C_6H_6 in this study.

Figure 3-1. Portable ambient air analyzer, MIRAN 1 BX.

(b) *High-volume Air Sampler*

Figure 3-2 shows a pictorial view of the high volume air sampler. In this sampler, air is drawn into a covered housing and it passes through a filter by means of a high flow-rate blower that allows suspended particles having diameters of less than 100 µm (stokes equivalent diameter) to pass to the filter surface.

Figure 3-2. High-volume air sampler, Andersen PM_{10}.

Particles within the size range of 100 to 0.1 μm diameter are ordinarily collected on glass fiber filters. The mass concentration of suspended particulate in the ambient air (μg/m^3) is computed by measuring the mass of collected particulate and the volume of air sampled.

(c) ***Sampling Train Analyzer***

Figure 3-3 shows the sampling train analyzer used for sampling SO_2 and NO_2. In this analyzer, sulfur dioxide is absorbed from air in a solution of potassium tetrachloromercurate (TCM), a dichlorosulfitomerculate complex, which resists oxidation by the oxygen in the air. The complex is reacted with pararosaniline and formaldehyded to form intensely colored pararosaniline methyl sulfonic acid. The absorbance of the solution is measured spectrophotometrically.

Figure 3-3. Sampling train analyzer, Paragon model 7007-00.

Ambient nitrogen dioxide is collected by bubbling air through a solution of sodium hydroxide and sodium arsenite. The concentration of nitrite ion (NO^-_2) produced during sampling is determined colorimetrically by reacting the nitrite ion with phosphoric acid, sulfanilamide and measuring the absorbance of the highly colored azodye at 540 nm. Collected samples are transferred to a laboratory for manual analysis.

(d) ***Spectrophotometer***

Infrared spectroscopy is one of the technique for analysis, inspection and education research about molecular structure of the matter such as solid, liquid and gas. This technique reports the data about vibration and rotation of molecules produced from infrared absorption of the matter.

Infrared ray is the region of electromagnetic spectrum with wavelengths region between visible and microwave (2.5 to 25 μm or 4,000 to 400 cm^{-1}). Infrared ray has the energy less than ultra violet ray but can classify better functional group of the matter's molecular structure. Most of conventional infrared spectrophotometers are dispersive instruments. In general, their components are: infrared source, sampling area, monochromator, infrared detector, and recorder or readout devices. Figure 3-4 presents this type of spectrophotometer which was used to analyze SO_2 and NO_2 in this study.

Figure 3-4. Spectrophotometer, BACHARACH Coleman model 35.

3.2 Estimation of Emission of Exhausts

Exhaust emission by a mobile source (say, vehicle type "i" for a pollutant type "j" in year "t") can be expressed using the equation (Shrestha and Malla, 1996).

$$M_{ij}(t) = N_i(t)\ F_i(t)\ FE_i(t)\ EF_{ik}\ S_i(t)\ A_i(t) \qquad (3\text{-}1)$$

Where $M_{ij}(t)$ = Exhaust emission by vehicle type "i" for pollutant type "j" in year "t"; (tonnes)

$N_i(t)$ = Number of vehicles in operation by vehicle type "i" in year "t"; (from Table 4-15)

$F_i(t)$ = Average fuel consumption by vehicle type "i" in year "t"; (L) (from Table 4-16)

$FE_i(t)$ = Fuel efficiency of vehicle type "i" in year "t"; (km/L) (from Table 4-16)

EF_{ik} = Exhaust emission factor expressed as the mass of pollutant per unit of distance traveled (g/km) (from Table 4-17)

$S_i(t)$ = Speed correction factor (defined as the pollutant-exhaust-emission rate at any speed to the pollutant-exhaust-emission rate at a specified speed, as determined by the 1975 Federal Test Procedure of U.S.A.) for vehicle type "i" in year "t";

$A_i(t)$ = Age-correction factor (defined as the ratio of pollutant-exhaust-emission rate at any vehicle-use status in km to the pollutant-exhaust-emission rate at a specified km): $A_i(t)$ is used to adjust for deterioration of vehicle performance with vehicle age.

$$vkm_i(t) = F_i(t)\, FE_i(t)\, S_i(t)\, A_i(t) \qquad (3\text{-}2)$$

Where $vkm_i(t)$ is known as average vehicle-kilometer traveled for vehicle type "i" in year "t".

Since fuel efficiency is a function of speed and vehicle age (US-EPA, 1973), the average vehicle-km traveled by vehicle type "i" in year "t".

Finally equation (3-1) can be written as

$$M_{ij}(t) = N_i(t)\, vkm_i(t)\, EF_{ik} \qquad (3\text{-}3)$$

In order to estimate the number of vehicles in operation in 1994 to 1999, a survey on various concerned organizations, such as, Nakhon Ratchasima provincial transport office for air conditioned as well as regular buses and other vehicles, and Nakhon Ratchasima provincial railway station for trains that pass through this municipality was done. Based on the records available in those offices and interviews with the officials in those offices, number of different type of vehicles were estimated. Amount of average fuel consumption by vehicle type was estimated on the basis of the field survey including interviews with the vehicle owners, drivers, fuel supply units, and other recorded information available in Nakhon Ratchasima municipality office.

In some cases, adoption of published information with certain modification or without any modification that suit the road/topographical condition of Nakhon Ratchasima municipality has also been made. Due to the lack of related specific emission factors with speed by vehicle category in Nakhon Ratchasima municipality, speed correction factor was assumed to be the same (i.e., $S_i(t) = 1$) for all types of vehicle. Similarly, $A_i(t)$ (age correction factor) has also been considered same for all vehicle types since exact vehicle registration data by vehicle type from the survey was not known.

Before making the estimation of these emission factors, consideration has been given to the emission standards of Thailand and its effectiveness, vehicle maintenance situation in Nakhon Ratchasima municipality. Because they influence largely the emission factors for mobile sources. In this way, emission standards of Thailand (1995), US-EPA emission factors (1973 and 1991), emission factors used for mobile sources in Kathmandu (Malla, 1996) and emission factors by Vitoonchavaritvong (1993) were considered for the estimation of emission factors of different pollutants from transports in Nakhon Ratchasima municipality.

Finally, total emission of exhausts by vehicle types for a particular year were estimated using equation (3-1) or (3-3) as given above.

To estimate the future emission of different pollutants under business-as-usual (BAU) scenario for the period 2001 to 2005, following assumptions were made: (i) exhaust emission factors (g/km) and vehicle-kilometer traveled for each type of the vehicle would be the same as that in 1999, and (ii) number of different types of transport in Nakhon Ratchasima municipality increases at a compounded growth rate per annum. This growth rate was evaluated using the data of last 6 years (1994 to 1999) except for motorcycles. In case of motorcycles, only the last 3 years data (1997 to 1999) were used due to data discrepancy in the earlier years.

Thus, the number of transport vehicles was calculated using the following equation:

$$V_p = V_b \ (1 + g_r)^{n_t} \tag{3-4}$$

Where,

V_p = number of a vehicle type in a year “t”.
V_b = number of a vehicle type in the base year.
n_t = number of year “t”.
g_r = compounded growth rate of a vehicle type.

3.3 Risk Assessment

3.3.1 Hazard Identification

Relationship between exposure and risk, in a quantitative way, can be obtained after attempting to find correlation between disease rates and various environmental factors. Preliminary data analysis of human studies, usually, involves setting up a simple 2×2 matrix such as the one shown in Table 3-2. The rows divide the populations according to those who have not been exposed to the risk factor. The columns are based on the numbers of individuals who have acquired the disease being studied and those who have not.

Various measures can be applied to the data given in Table 3-2 to see whether they suggest an association between exposure and disease. They are relative risk, attributable risk and odds ratio. The calculation approaches for each of them using the data in Table 3-2 are as follows.

Table 3-2. A 2×2 matrix for an epidemiologic rate comparison.

	With disease	Without disease
Exposed	*a*	*b*
Not exposed	*c*	*d*

- The *relative risk* is defined as

$$Relative \quad risk \quad = \quad \frac{a/(a+b)}{c/(c+d)} \qquad (3-5)$$

In the equation (3-5) numerator is the fraction of those exposed who have the disease, and the denominator is the fraction of those exposed who do not have the disease. When numerator is equal to denominator, the relative risk would be 1.0. Above 1.0, the higher the relative risk the more the data suggests an association between exposure and risk.

- The *attributable risk* is defined as

$$Attributable \quad risk \quad = \quad \frac{a}{a+b} - \frac{c}{c+d} \qquad (3-6)$$

The attributable risk is the difference between the odds of having the disease with exposure and the odds of having the disease without exposure. An attributable risk of 0.0 suggests no relationship between exposure and risk.

- The *odds ratio* is defined as the cross product of the entries in the matrix:

$$Odds \quad ratio \quad = \quad \frac{ad}{bc} \qquad (3-7)$$

The odds ratio is similar to the relative risk. Number above 1.0 suggest a relationship between exposure and risk.

3.3.2 Dose-response Assessment

The fundamental goal of a dose-response assessment is to obtain a mathematical relationship between the amount of a toxicant that a human was exposed to and the risk that there would be an unhealthy response to that dose.

Potency Factor for Carcinogens

For chronic toxicity studies, a low dose is administered over a significant portion of the animal's lifetime. The resulting dose-response curve has the incremental risk of cancer, the slope of the dose-response curve is called the *potency factor* (PF), or slope factor. As mentioned in the literature review in Chapter II, benzene, an exhaust from transports, is a carcinogenic chemical. The risk of carcinogenic substance can be calculated in the following way (Masters, 1990).

$$Potency \quad factor \quad = \quad \frac{Incremental \quad lifetime \quad cancer \quad (risk)}{Chronic \quad daily \quad \text{int}\,ake \quad (mg/kg-day)} \qquad (3-8)$$

The denominator in equation (3-8) is the dose average over an entire lifetime; it has units of average milligrams of toxicant absorbed per kilogram of body weight per day, which is usually expressed in mg/kg-day. Since risk has no units, the units for potency factor are therefore $(mg/kg\text{-}day)^{-1}$.

If a dose response curve is available, potency factor can be found from the slope. In fact, one interpretation of the potency factor is that it is the risk produced by a chronic daily intake of 1 mg/kg-day, as shown in Figure 3-5.

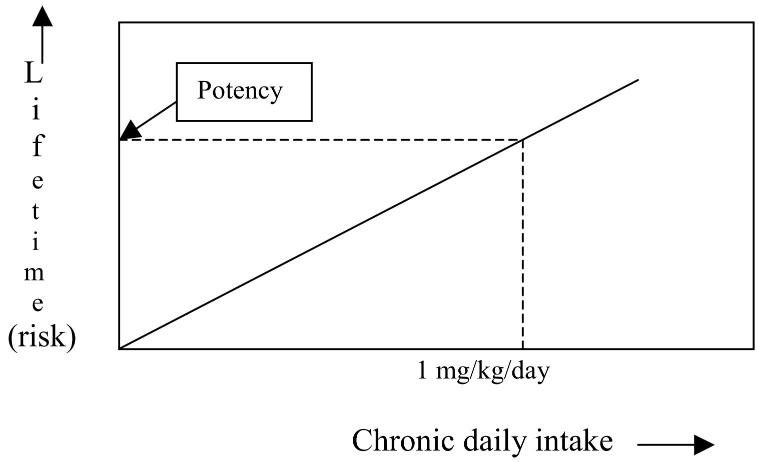

Figure 3-5. The potency factor was the slope of the dose-response curve.

Rearranging equation (3-8), one can calculate the incremental lifetime cancer risk by multiplying the chronic daily intake, CDI (based on exposure data) by the potency factor (from US-EPA database). In this way, one can obtain equations (3-9) and (3-10) below.

$$Incremental\ lifetime\ cancer\ risk = CDI \times potency\ factor \qquad (3-9)$$

$$CDI(mg/kg-day) = \frac{Average\ \ daily\ \ dose\,(mg/day)}{Body\ \ weight\ \ (kg)} \qquad (3-10)$$

The linearized multistage risk-response model assumptions built into equation (3-10) should make this value an upper-bound estimate of the actual risk. Additionally, the above equation estimates the risk of getting cancer, so it should be even more conservative as an upper bound estimate of cancer death rates. In this study, risk assessment of benzene in ambient air (road side) of Nakhon Ratchasima municipality has been considered. The seven day average benzene concentration (hourly data) obtained at the sampling station A5, i.e., 1.51 mg/m^3 (which is higher than that at sampling location A6) has been considered for risk calculation. Data on daily intake volume, exposure frequency, and exposure duration for commercial places have been considered as 20 m^3/day, 250 days/year, and 25 years, respectively (Masters, 1990). These data were recommended by US-EPA. Average age (life expectancy in Thailand) is considered as 69 (Asiaweek, 2000), and the average body weight in the context of Thailand has been considered as 60 kg (Health Department, 1998). Similarly the potency factor is considered as 2.9×10^{-2} mg/kg-d)$^{-1}$. The usual goal of risk has been considered as 10^{-6} as suggested by US-EPA (Masters, 1990).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Analysis of Ambient Air Samples

Sampling was done in two stages: preliminary study and in-depth study.

4.1.1 Preliminary Study

Six one-hourly ambient air samples for each of the CO and C_6H_6, and one twelve-hourly ambient air sample for each of the SO_2, NO_2 , and PM_{10} in each of the six locations as mentioned in chapter III (one location per day during the period 8 to 16 November 1999) were taken. Table 4-1 and Figures 4-1 and 4-2 demonstrate the maximum concentrations of different pollutants at each of the six locations considered, where the concentrations of different pollutants are compared with their respective ambient air standard of Thailand (1995) except for benzene and NO_2.

For benzene, American Conference of Governmental industrial Hygienists (ACGIH) Standard (ACGIH, 1996) has been considered since Thailand has no own ambient standard for this pollutant. In case of NO_2, since Thailand has only one hour average standard, 24 hour average standard of Japan (Lohani, 1984) was considered. Details of the ambient air samples taken are given in appendix D.

Table 4-1. Average maximum concentrations of different pollutants in ambient air samples.

Station	CO		C_6H_6		SO_2		NO_2		PM_{10}	
	Sample (ppm) (1 h)	STD ppm	Sample (ppm) (1 h)	STD ppm	Sample (ppm) (12 h)	STD ppm	Sample (ppm) (12 h)	STD ppm	Sample ($\mu g/m^3$) (12 h)	STD $\mu g/m^3$
A1	4.71	30	4.12	10	9.96×10^{-5}	0.12	9.93×10^{-5}	0.04	57.94	120
A2	4.86	(1 h)	4.72	(1 h)	706×10^{-5}	(24 h)	0.39×10^{-5}	(24 h)	368.34	(24 h)
A3	7.72		3.17		0.10		4.85×10^{-5}		173.39	
A4	4.05		3.13		511×10^{-5}		4.05×10^{-5}		211.87	
A5	8.86		3.66		37.6×10^{-5}		3.83×10^{-5}		342.16	
A6	14.96		10.24		327×10^{-5}		3.32×10^{-5}		186.77	
Avg	7.53		4.84		0.05		4.40×10^{-5}		223.41	

It has been noticed that the maximum concentrations of CO, C_6H_6, SO_2, and NO_2 in the ambient air were in the range of 4.05 to 14.96 ppm, 3.13 to 10.24 ppm, 9.96×10^{-5} to 0.10 ppm, and 0.39×10^{-5} to 9.93 ppm, respectively. The one-hourly average maximum concentrations of CO and C_6H_6 were 7.53 ppm, and 4.84 ppm, respectively. Similarly the 12-hourly average maximum concentrations of SO_2, and NO_2 were 0.05 ppm and 4.40×10^{-5} ppm, respectively. In case of PM_{10}, the maximum concentration range was in between 57.94 to 368.34 µg/m^3, and the 12-hourly average maximum concentration was 223.41 µg/m^3.

The highest CO concentration in ambient air was found at station A6 and then at station A5. In case of C_6H_6 also, the highest concentration was at station A6. But the second highest value was at station A2. The highest concentration of PM_{10} in the ambient air was at station A2 and then at station A5. In case of SO_2, the highest concentration was at station A3 followed by station A2. For NO_2, concentration was highest at station A1 and then at A3. From Table 4-1 and Figures 4-1 to 4-3, it is noticeable that although the concentrations of pollutants, such as CO, SO_2, and NO_2 are within their ambient standard limits, concentrations of PM_{10} (except at station A1) exceeded the ambient standard. C_6H_6 in the ambient air sample has exceeded its standard at station A6.

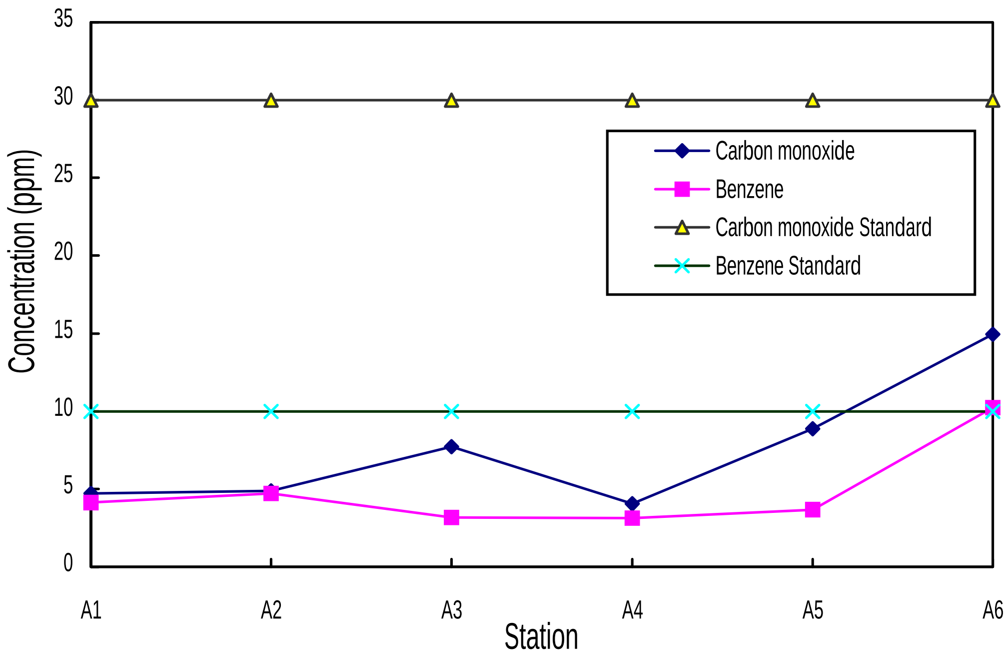

Figure 4-1. Average maximum concentrations of CO (1 h) and C_6H_6 (1 h) at six sampling stations.

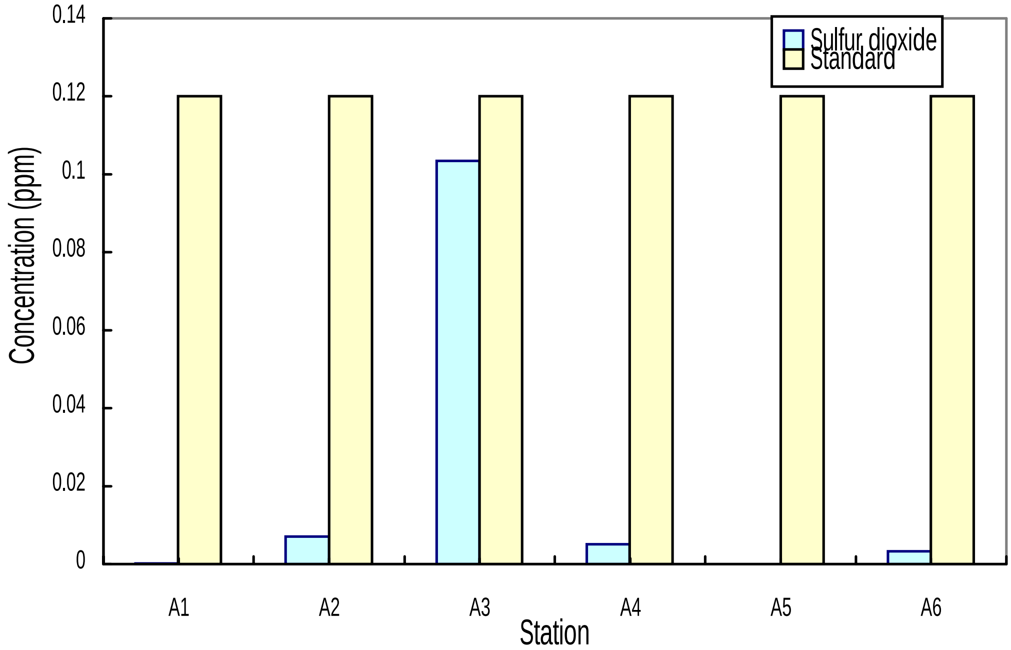

Figure 4-2. Average maximum concentration of SO_2 at six sampling stations.

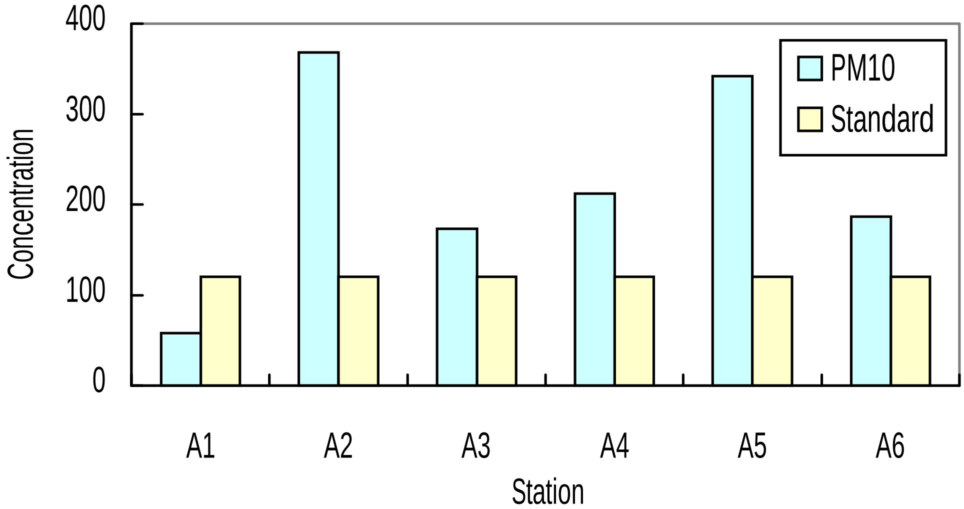

Figure 4-3. 12 hourly PM_{10} concentrations ($\mu g/m^3$) at six sampling stations.

4.1.2 In-depth Study

Two locations which had mostly high concentration values of different pollutants in the ambient air and where there was heavy traffic and narrow roads etc., were selected for in-depth study. The selected locations were station A5 (Ratchasima-Chokchai road) and A6 (Chomphon road near night bazaar).

Since the meteorological parameters (mainly, wind direction and wind speed), and number and type of vehicles plying on the nearby roads affect the concentrations of pollutants in the ambient air measured (near road-side) of a sampling station, their description is important while discussing the ambient air sampling results. In the followings, short descriptions of meteorological information of Nakhon Ratchasima municipality, and number and type of vehicles plying on the road near the sampling stations A5 and A6 are presented, before explaining the results of the ambient air samples analyses.

Meteorological information. Table 4-2 presents the different meteorological data of Nakhon Ratchasima municipality during the sampling period 25 November to 8 December 1999 at stations A5 and A6.

Among the different parameters, wind speed and its direction may influence measured concentrations of different pollutants in the ambient air (road-side), such as PM_{10}. At station A5, wind speed was high on the last 3 sampling days (29 Nov. to 1 Dec. 99) compared to earlier days. In station A6, wind speed was high on first, fifth and seventh days of sampling. In both stations, wind direction was almost north-easterly. This can be further clearly noticed from the Figure 4-3.

Table 4-2. The major meteorological data in Nakhon Ratchasima municipality during 25 November to 8 December 1999.

Date	Wind direction	Wind speed (km/h)	Temperature (°C)	Relation humidity (%)	Atmospheric pressure (mm.Hg)
25 Nov.	Easterly wind	4.38	27.6	72.6	88.8
26 Nov.	Easterly wind	2.13	27.1	70.1	88.8
27 Nov.	Northeasterly	3.88	26.5	65.5	89.3
28 Nov.	Northeasterly	3.88	25.9	69.0	90.2
29 Nov.	Northeasterly	9.63	26.0	57.9	91.8
30 Nov.	Northeasterly	8.00	23.2	61.4	92.3
1 Dec.	Northeasterly	8.25	23.0	60.4	93.4
2 Dec.	Northeasterly	7.63	18.0	61.0	94.0
3 Dec.	Northeasterly	4.50	21.8	72.1	94.0
4 Dec.	Northeasterly	3.88	23.7	70.6	93.0
5 Dec.	Northeasterly	4.75	23.0	71.4	92.6
6 Dec.	Northeasterly	8.50	22.3	65.5	93.8
7 Dec.	Northeasterly	5.13	22.8	62.6	94.5
8 Dec.	Northeasterly	7.88	22.3	61.1	94.9

Source: Nakhon Ratchasima Provincial Meteorological Station (1999).

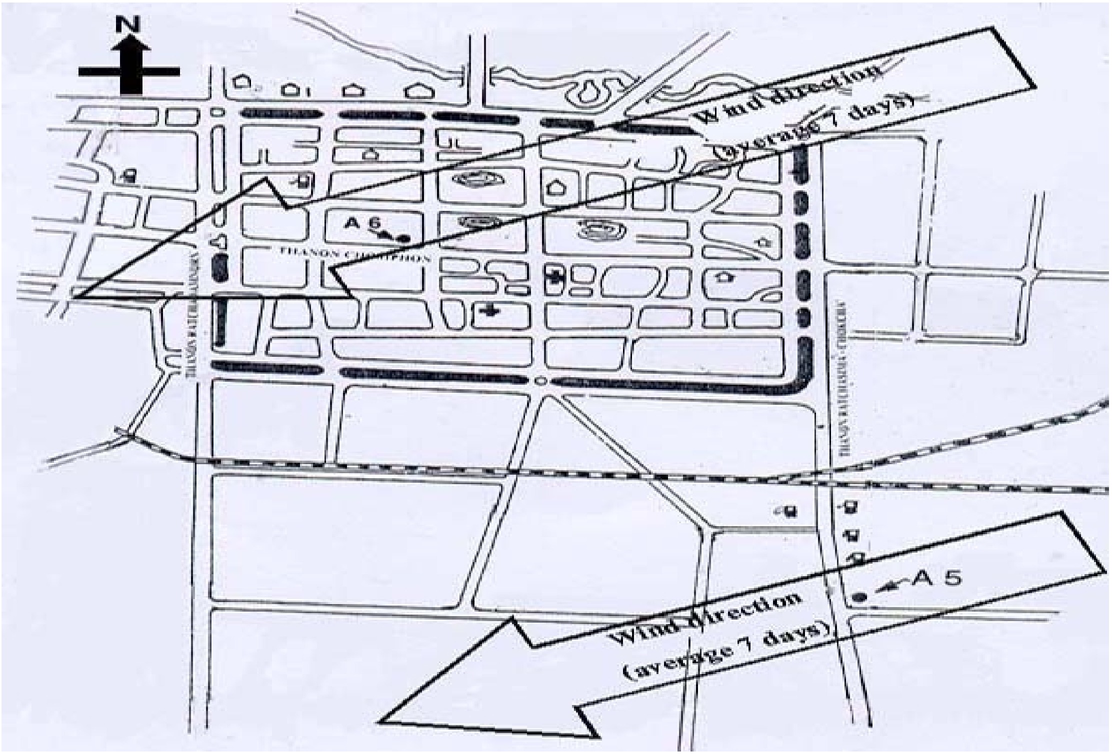

Figure 4-4. Wind direction at 11.50 m level at stations A5 and A6.

Number and type of vehicles at stations A5 and A6. Number and type of vehicles plying on the roads near to the sampling stations influence the concentrations of different pollutants in the ambient air of those stations. If the number of the vehicles is large, concentration of pollutants could be high. At the same time, different types of the vehicles may emit different quantity of pollutants for the same distance traveled or they have different emission factors. For example, motorcycles, trucks emit high amount of particulate matters than buses or cars. Much more carbon monoxide and hydro-carbon are emitted by buses, trucks, motorcycles, 3-wheelers than by cars, pick-ups etc. (for detail, see Table 4-17). Table 4-3 presents one hourly mean number and type of vehicles (mean of six data) plying on the road at samplings station A5 during the period 25 November to 1 December 1999. Number of total vehicles plying were large on all days except on Saturday and Sunday. In those two days, number of buses & trucks, pick-ups and cars were plying on the roads near to station A5 was also less.

Table 4-3. Mean one hourly number of vehicles plying on the road at station A5 (25 Nov. to 1 Dec. 1999).

day		Vehicle type					
		Motor cycle	3-wheeler	Car	Pick-up	Bus & truck	Total
Thursday	1	708	44	403	1212	225	2592
Friday	2	754	52	468	1150	236	2660
Saturday	3	633	43	366	1089	197	2328
Sunday	4	559	45	349	978	162	2093
Monday	5	486	35	280	1663	237	2701
Tuesday	6	541	43	335	1425	262	2606
Wednesday	7	708	46	416	1417	233	2820

Source: Nakhon Ratchasima Provincial Meteorological Station (1999).

Table 4-4 presents one hourly mean number and type of vehicles plying on the road at samplings station A6 during the period 2 to 8 December 1999. Here too,

Table 4-4. Mean one hourly number of vehicles plying on the road at A6 (2 to 8 December 1999).

day		Vehicle type					
		Motor cycle	3-wheeler	Car	Pick-up	Bus & truck	Total
Thursday	1	509	62	320	648	27	1566
Friday	2	482	56	331	704	24	1597
Saturday	3	379	48	264	542	24	1257
Sunday	4	277	58	234	384	18	971
Monday	5	300	51	171	499	21	1042
Tuesday	6	371	60	290	753	25	1499
Wednesday	7	430	59	296	642	33	1460

Source: Nakhon Ratchasima Provincial Meteorological Station (1999).

number of vehicles plying was large on all days except on Saturday and Sunday. From the Tables 4-3 and 4-4, it is clearly noticeable that mean one hourly number of vehicles plying on the roads near to station A5 were large compared to the same near to station A6. This indicates that the concentration of pollutants in the ambient air at station A5 should be higher than those at station A6.

Analyses of ambient air samples. A total of forty-two one-hourly ambient air samples for each of the CO and C_6H_6 (six samples per day per location for a week), six twelve hourly ambient air samples (one sample per day per location for six days), and one twenty-four hourly ambient air samples for each of the SO_2, NO_2, and PM_{10} in each of the two locations (A5 and A6) were taken and analyzed. The results are presented in Tables 4-5 to 4-14 and Figures 4-5 to 4-10. The concentrations of each pollutant in the above tables and figures have been compared with the corresponding ambient standard of Thailand (1995) except for C_6H_6 and NO_2.

Table 4-5 and Figure 4-5 represent the one-hourly concentrations of CO at station A5. At this station, the maximum concentration of CO during 25 November to 1 December 1999 was in the range of 4.02 to 11.03 ppm and the one-hourly average concentration was in the range of 0.90 to 3.54 ppm. Average or maximum concentration of CO was highest on sixth day of sampling while the same was lowest on fourth day of sampling.

Table 4-5. One-hourly CO concentrations at station A5 (ppm).

Day	Station A5 (25 Nov. to 1 Dec. 1999)						
	1	2	3	4	5	6	7
Max.	4.68	4.87	5.96	4.02	6.10	11.03	8.91
Avg.	1.80	1.19	2.44	0.90	1.81	3.54	1.02
Min	0.81	0.00	0.00	0.01	0.28	0.05	0.00
STD.	30 ppm.						

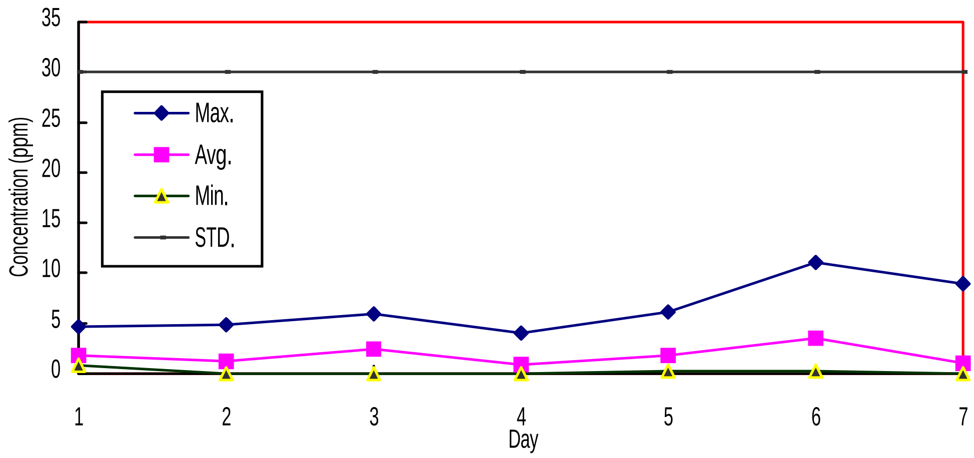

Figure 4-5. One hourly concentrations of CO at stations A5 (25 Nov. to 1 Dec. 99).

Table 4-6 and Figure 4-6 show the one-hourly concentrations of CO at station A6. At this station, the one-hourly maximum concentrations of CO during the period 2 to 8 December 1999 were in between 2.91 to 12.98 ppm, and the average concentrations were in the range of 0.46 to 2.21 ppm. The average CO concentration was highest on the first day of sampling and this was lowest on the fifth day of sampling.

Table 4-6. One-hourly CO concentrations at station A6 (ppm).

Day	Station A6 (2 to 8 Dec. 1999)						
	1	2	3	4	5	6	7
Max.	10.32	12.98	6.29	7.50	2.91	7.93	3.93
Avg.	2.21	1.44	0.65	1.44	0.46	1.02	0.86
Min.	0.32	0.00	0.11	0.00	0.00	0.07	0.16
STD.	30 ppm.						

Although the variations in maximum or average concentration of CO in both stations were not large, they were somehow influenced by number and type of the vehicles plying on the roads nearby to those stations. In case of station A5, the variations in concentration might also the result of wind speed which was north-easterly and road construction activity near the station during the sampling period. It can be clearly observed that in both stations, the concentrations of CO were far below the corresponding ambient standard of Thailand.

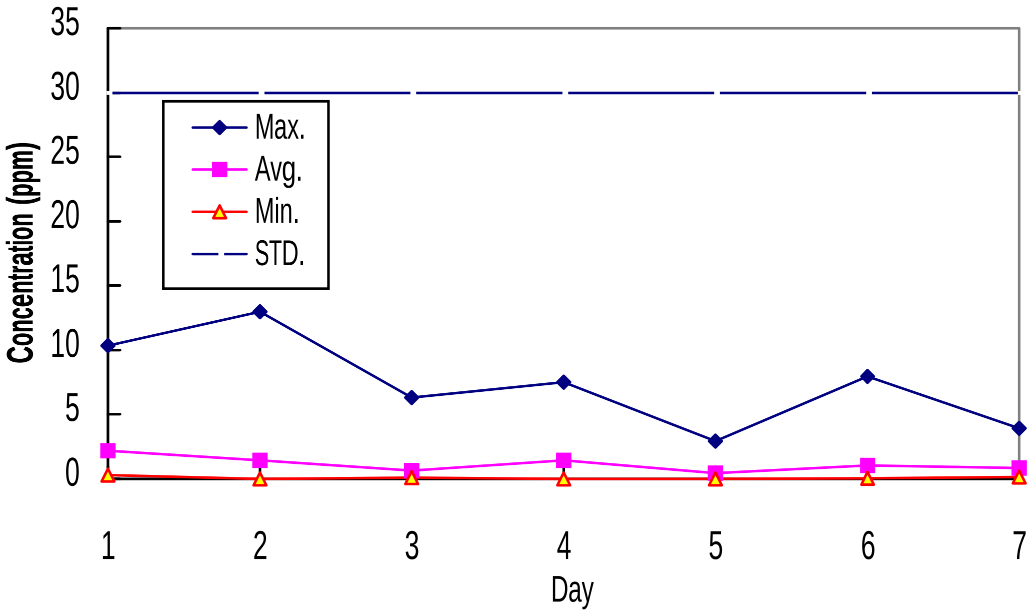

Figure 4-6. Average one-hourly concentrations of CO at station A6 (2 to 8 Dec. 1999).

Table 4-7 and Figure 4-7 present the one-hourly concentrations of C_6H_6 at station A5. The one-hourly maximum and average concentrations of C_6H_6 at this station were in the range of 1.07 to 4.16 ppm and in the range of 0.05 to 2.15 ppm, respectively.

Table 4-7. Average one-hourly C_6H_6 concentrations at station A5 (ppm).

Day	Station A5 (25 Nov. to 1 Dec.1999)							
	1	2	3	4	5	6	7	Avg.
Max.	3.42	3.70	1.07	3.64	3.59	4.16	2.77	3.19
Avg.	1.79	1.38	0.05	2.15	2.01	1.88	1.32	1.51
Min	0.20	0.00	0.00	0.94	1.04	0.22	0.00	0.69
STD.	10 ppm							

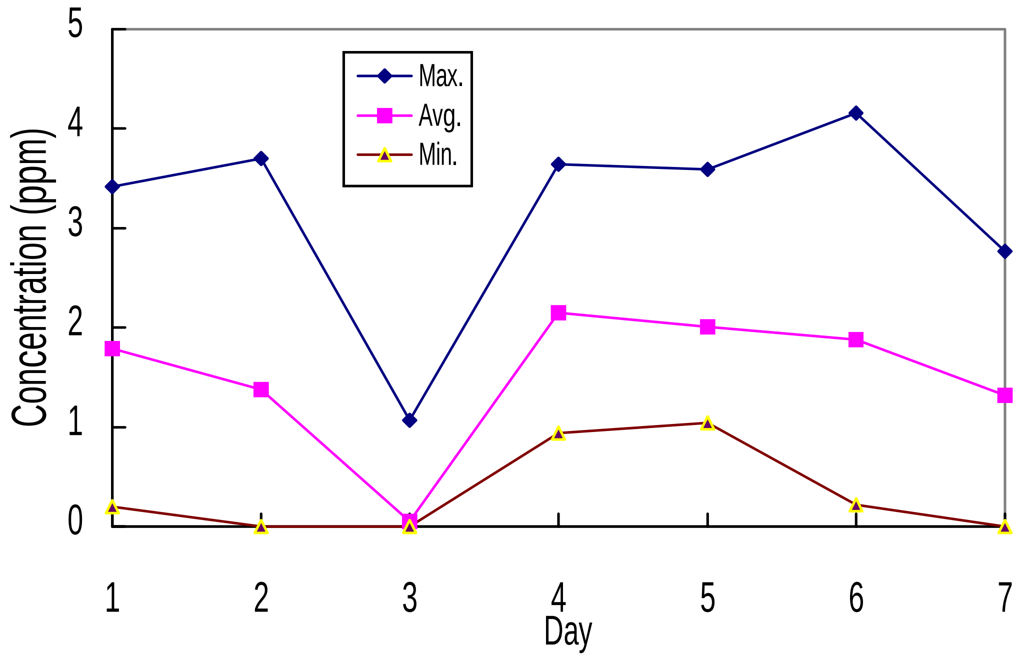

Figure 4-7. Average one-hourly concentrations of C_6H_6 at station A5 (2 Nov. to 1 Dec. 1999).

Similarly, Table 4-8 and Figure 4-8 present the one-hourly concentrations of C_6H_6 at station A6. The maximum and average concentrations of C_6H_6 in this station were in the range of 0.46 to 3.85 ppm and in the range of 0.04 to 1.98 ppm, respectively.

Table 4-8. Average one-hourly C_6H_6 concentrations at station A6 (ppm).

Day	Station A6 (2 to 8 Dec. 1999)							
	1	2	3	4	5	6	7	Avg.
Max.	3.85	1.44	0.46	2.09	1.21	2.41	2.76	2.03
Avg.	1.98	0.28	0.04	0.43	0.19	0.75	0.86	0.65
Min.	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.05
STD.	10 ppm.							

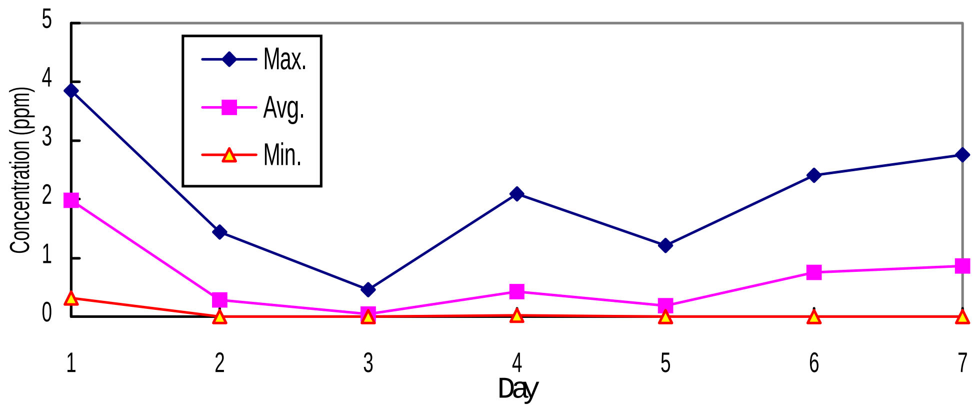

Figure 4-8. Average one-hourly concentrations of C_6H_6 at station A6 (2 to 8 December 1999).

As in case of C_6H_6, variations in average and maximum concentrations of C_6H_6 in station A5 were influenced by number and type of vehicles plying on the nearby roads as well as wind speed and wind direction, and road construction activities. However, in station A6, it is mostly influenced by the number and type of vehicles. It can be noticed that the concentrations of C_6H_6, however, in both stations were far below the ACGIH standard.

Table 4-9 and 4-10 demonstrate the SO_2 concentrations at stations A5 and A6, respectively. At station A5, twelve-hourly concentrations of SO_2 were in the range of 49.3×10^{-5} to 199×10^{-5} ppm, and the 24-hourly concentration of SO_2 was 110×10^{-5} ppm.

Table 4-9. SO_2 concentrations at station A5 (ppm).

Day	Station A5 (25 Nov. to 1 Dec.1999)					
	1	2	3	4	5	6
12 hourly	137×10^{-5}	86.9×10^{-5}	199×10^{-5}	123×10^{-5}	49.3×10^{-5}	110×10^{-5} (24 h)
STD.	0.12 ppm. (24 h)					

At station A6, the twelve-hourly concentrations of SO_2 were in the range of 48.7×10^{-5} to 256×10^{-5} ppm, and the 24-hourly concentration of SO_2 was 97.4×10^{-5} ppm. The concentrations of SO_2 in both stations were quite low in comparison to the standard.

Table 4-10. SO_2 concentrations at station A6 (ppm).

Day	Station A6 (2 to 8 Dec.1999)					
	1	2	3	4	5	6
12 hourly	256×10^{-5}	197×10^{-5}	86×10^{-5}	48.7×10^{-5}	159×10^{-5}	97.4×10^{-5} (24 h)
STD.	0.12 ppm. (24 h)					

Table 4-11 and 4-12 present concentrations of NO_2 at sampling stations A5 and A6, respectively. At station A5, the 12-hourly concentrations of NO_2 were in the range 0.30×10^{-5} to 4.77×10^{-5} ppm, and the 24-hourly concentration was 2.98×10^{-5} ppm.

Table 4-11. NO_2 concentrations at station A5 (ppm).

Day	Station A5 (25 Nov. to 1 Dec.1999)					
	1	2	3	4	5	6-7
12 hourly	3.66×10^{-5}	4.02×10^{-5}	3.77×10^{-5}	0.30×10^{-5}	4.77×10^{-5}	2.98×10^{-5} (24 h)
STD.	0.04 ppm. (24 h)					

At station A6, the 12-hourly concentrations of NO_2 were in the range 2.65×10^{-5} to 4.51×10^{-5} ppm, and the 24-hourly concentration was 3.51×10^{-5} ppm. As in case of NO_2, NO_2 concentrations in both stations were very low and thus, far below the corresponding standard.

Table 4-12. NO_2 concentrations at station A6 (ppm).

Day	Station A6 (2 to 8 Dec.1999)					
	1	2	3	4	5	6 - 7
24 hourly	4.51×10^{-5}	2.65×10^{-5}	4.19×10^{-5}	3.50×10^{-5}	2.97×10^{-5}	3.51×10^{-5} (24-h)
STD.	0.04 ppm. (24 h)					

Table 4-13 and Figure 4-9 present the concentrations of PM_{10} during the period 25 November to 1 December 1999 at station A5. In this station, the 12-hourly concentrations of PM_{10} during the period 25 to 29 November 1999 were in the range 89.44 to 359.30 $\mu g/m^3$, and the one 24-hourly concentration of the same from 30 November to 1 December was 209.43 $\mu g/m^3$.

Table 4-13. PM_{10} concentrations at station A5 ($\mu g/m^3$).

Day	Station A5 (25 Nov. to 1 Dec. 1999)					
	1	2	3	4	5	6-7
24 hourly	89.44	195.59	239.94	198.58	359.30	209.43 (24h)
STD.	120 $\mu g/m^3$ (24 h)					

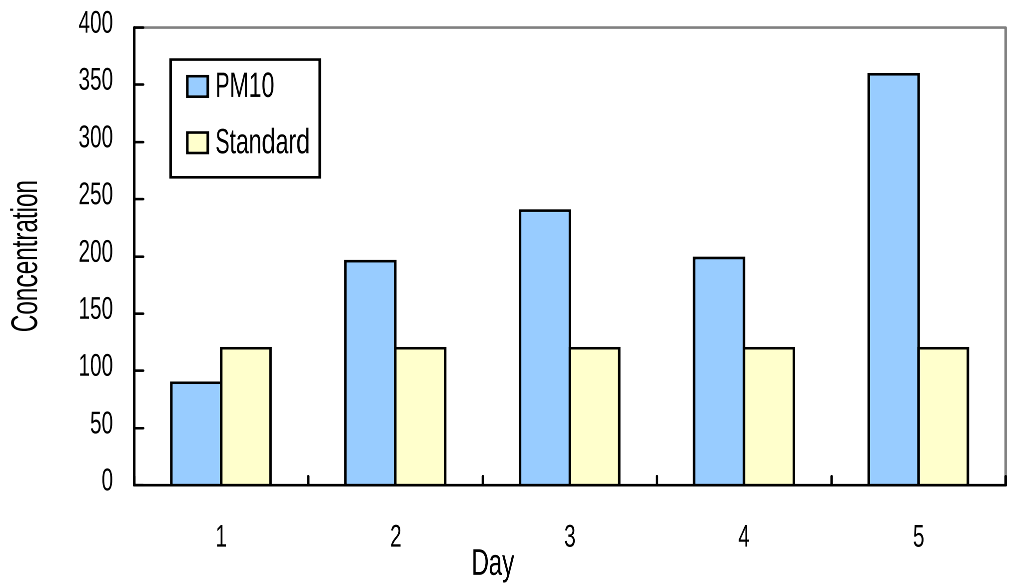

Figure 4-9. 12 hourly PM_{10} concentrations ($\mu g/m^3$) at station A5 during 25 Nov. to 1 Dec.1999.

Table 4-14 and Figure 4-10 demonstrate the PM_{10} concentrations at station A6. The 12-hourly concentrations of PM_{10} during the period 2 to 6 December 1999 were in the range 63.07 to 150.22 $\mu g/m^3$, and the 24-hourly concentration from 7 to 8 December was 83.59 $\mu g/m^3$ in this station.

Table 4-14. PM_{10} concentrations at station A6 ($\mu g/m^3$).

Day	Station A6 (2 to 8 Dec.1999)					
	1	2	3	4	5	6-7
12 hourly	109.80	150.22	100.47	86.65	63.07	83.59 (24h)
STD.	120 $\mu g/m^3$ (24 h)					

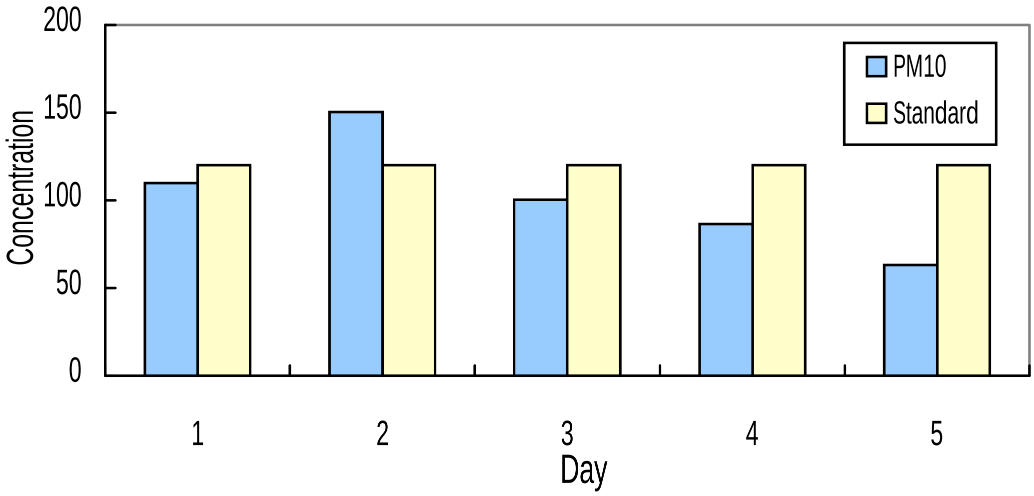

Figure 4-10. 12 hourly PM_{10} concentrations (µg/m^3) at station A6 during 2 to 8 December 1999.

In case of PM_{10}, both 12-hourly and 24-hourly concentration values have exceeded the standard at station A5 except on the first day of the sampling. However at station A6, surprisingly, all 12 hourly samples (except on the third day of sampling) and 24-hourly sample were within the limit of corresponding 24 hourly ambient air standard of Thailand.

During the sampling period, there was some road construction works going on near station A5. Moreover, vehicles plying on the roads at location A5 were found mostly at high speed. Additionally, number and types of vehicles plying on the roads near to this station were large, and wind speed was also moderate. These factors might have enhanced concentrations of PM_{10} measured and thus, exceeded the ambient air standard of Thailand at this station. At station A6, in only one day, the PM_{10} concentration in the ambient air exceeded the corresponding standard. That day was a weekend day and therefore, there was more movement of vehicles as well as people who came for shopping to the night bazaar.

Based on the information from the Pollution Control Department (1999), a comparison between maximum concentrations of different pollutants present in the ambient air of Nakhon Ratchasima and other cities of Thailand was done. It has been noted that CO concentration (6.5 ppm) in Nakhon Ratchasima was lower than those in Bangkok and Saraburi (13.0 and 8.5 ppm, respectively). SO_2 concentration in Nakhon Ratchasima (199 ppb) was found higher than those in Bangkok and Cholburi (177 and 27 ppb, respectively). The concentration of NO_2 in Nakhon Ratchasima (4.77 ppb) was lower than those in Bangkok and Khonkaen (141.8 and 65.0 ppb, respectively). At the sametime, the concentration of PM_{10} in Nakhon Ratchasima municipality (359.3) was higher than those in Bangkok and Khonkaen (224.6 and 87.7 µg/m^3, respectively). The details of the above described ambient air quality of different cities is given in Table A-3 (appendix A).

4.2 Emission of Air Pollutants from Mobile Sources

4.2.1 Estimation of Number of Vehicles and Vehicle Kilometer Traveled

Table 4-15 presents the number of different kinds of vehicles plying on the roads of Nakhon Ratchasima municipality for the years 1994, 1995, 1996, 1997, 1998, and 1999. The figures in the Table were estimated based on the information provided by different agencies located in the Nakhon Ratchasima municipality (such as Nakhon Ratchasima Provincial Transport Office and Railway Office).

From Table 4-15, it is noticeable that the number of private pick-ups and cars have certain growth during the period 1994 to 1999. The number of motorcycles had remarkable growth during the period 1994 to 1996. However, there is a tremendous decrease in their number in 1997 to 1999. The reason for this might be the effect economic crisis in Thailand in that period. Some workers were relieved from their jobs resulting in no income and ability to pay money back to financial company for their loan and so on.

Table 4-15. Vehicle types and their numbers in Nakhon Ratchasima municipality.

Types of vehicle	Year					
	1994	1995	1996	1997	1998	1999
Air cond. bus	2,357	2,357	2,357	2,357	2,357	2,357
Regular bus	3,599	3,599	3,599	3,599	3,599	3,599
Hire pick up	2,331	2,331	2,331	2,331	2,331	2,331
Private pick- up	46,466	60,460	65,322	60,075	54,809	56,952
Car	12,679	19,113	23,044	21,172	21,616	22,114
Truck	7,188	8,416	9,664	8,664	6,721	7,601
3-wheeler	973	1,039	1,058	949	989	989
Motorcycle	208,904	273,760	325,815	147,113	148,718	178,463
Train	47	47	47	47	47	47
Total	284,544	371,122	433,237	246,307	241,187	274,453

Source: Results from the study (details in appendix A and C Tables A-1, A-2, and C-1 to C-8).

In the year 1999, number of motorcycles had again risen compared to the years 1997 and 1998 as the economy started to pick up. However, this number is still much lower compared to that in the year 1996. Table 4-16 presents the estimated amount of average fuel consumption, and average vehicle-kilometer traveled by vehicle type in the year 1999.

From Table 4-16 it is noticeable that both total fuel consumption amount and vehicle-kilometer traveled distance are largest by the vehicle type "motorcycle" in 1999 as in the past (appendix B Table B-18 to B-41 (for 1994 to 1998)).

Table 4-16. Average fuel consumption and vehicle kilometer traveled in 1999.

Vehicle types	Parameters		
	Average fuel consumption (liter)	Average vehicle kilometer traveled (km)	Fuel efficiency (km/liter)
Air cond. bus	3,332,798	11,099,113	3.33
Regular bus	4,066,870	13,420,671	3.30
Hire pick up	892,773	7,592,067	8.50
Private pick- up	29,102,472	291,024,720	10.00
Car	8,071,610	96,859,320	12.00
Truck	5,548,730	24,969,285	4.50
3-wheeler	1,742,618	25,267,961	14.50
Motorcycle	16,418,596	521,111,960	31.74
Train	479,256	119,803	0.25

Source: Results from the study (details in appendix B Tables B-6, B-42 to B-46).

The price of the motorcycle is low and many people with medium income and even a small group of low income people are able to easily afford buying it. Motorcycle is a popularly used vehicle in this city. Private pick-up vehicles and cars are at the second and third positions, respectively in terms of both fuel consumption amount and vehicle-kilometer traveled distance in 1999.

4.2.2 Estimation of Exhaust Emission Factors

Exhaust emission factor for mobile source is expressed as the mass of a pollutant emitted per unit of distance traveled. Table 4-17 summarizes the emission factor for mobile sources considered in this study. Emission factors presented in this table were derived from various sources and adopted to the conditions of Nakhon Ratchasima municipality to a maximum possible level as described in the methodology section.

Table 4-17. Emission factors for mobile source used for of Nakhon Ratchasima municipality (g/km).

Fuel type	Vehicle type	CO	SO_2	NO_2	HC	PM_{10}
Diesel	Air bus	12.0	1.75	13.0	3.7	1.5
	Reg. bus	12.0	1.75	13.0	3.7	1.5
	pick up	6.90	0.39	1.4	1.70	0.25
	Truck	12.0	1.75	13.0	3.7	6.21
	Rail	12.0	1.75	13.0	3.7	6.21
Gasoline	Car	2.72	0.13	2.7	0.97	0.14
	Motorcycle	13.0	0.02	0.20	5.0	5.59
LPG	3–wheelers	13.0	0.50	1.2	4.5	1.85

Source: Results from the study (details in appendix B Tables B-1 to B-4).

4.2.3 Emission Quantity of the Pollutants

Based on the information in sub-sections above, the amount of the different pollutants' emission by vehicle type in the year 1999 was calculated using the equation (3-3) given in chapter III. Table 4-18 demonstrates the emission quantity (tonnes) of different air pollutants by vehicle type in the year 1999.

From the table, it is highly remarkable that the emission of carbon monoxide (CO), a hazardous pollutant, has a largest share (54.3%) among the different types of pollutants considered.

The second position has been captured by hydrocarbon, HC (19%). Shrestha and Malla (1993) also estimated the emission share of CO and HC in Kathmandu in 1993, as 65% and 30%, respectively. Motorcycles followed by the pick-ups had great responsibility for such high emission of CO and HC in Nakhon Ratchasima municipality.

Table 4-18. Quantity of exhaust emission by vehicle type in 1999.

Vehicle type	Pollutants (tonnes)						
	CO	SO_2	NO_2	HC	PM_{10}	Total	%
Bus	294	42	318	91	37	782	4.2
Pick up	2,060	114	418	508	75	3,175	17.2
Truck	300	44	325	92	155	916	5.0
Train	1	0.2	2	0.4	1	5	0.03
Car	263	13	262	94	14	646	3.5
Motorcycle	6,774	10	104	2,606	2,913	12,407	67.2
3 – wheelers	328	13	30	114	47	532	2.9
Total	10,020	236.2	1,459	3,505.4	3,242	18,463	
%	54.3	1.3	7.9	19.0	17.8		100

Table 4-19 summarizes the total quantity of exhaust emission in the previous years (1994, 1995, 1996, 1997, and 1998).

Table 4-19. Total quantity of emission of pollutants (tonnes) in 1994 to 1998.

Years	Pollutants type (tonnes)					
	CO	SO_2	NO_2	HC	PM_{10}	Total
1994	10,672	208	1,272	3,811	3,710	19,673
1995	13,775	386	1,541	4,929	4,819	25,450
1996	16,025	438	1,706	5,765	5,702	29,636
1997	8,958	245	1,496	3,078	2,753	16,530
1998	8,781	227	1,389	3,039	2,734	16,170

Source: Results from the study (see appendix B, Table B-8 to B-13).

While estimating the information in the above table or in the Tables B-7 to B-11 of appendix B, the exhaust emission factors and average vehicle-kilometers traveled were considered same as in the year 1999. Table 4-20 shows the total emission of different pollutants by fuel type (tonnes) in 1999.

Table 4-20. Pollutants emission by fuel type in 1999.

Fuel type	Pollutant type (tonnes)					
	CO	SO_2	NO_2	HC	PM_{10}	Total
Gasoline	7,037	23	366	2,700	2,927	13,053
Diesel	2,655	200.20	1,063	691	268	4,877.2
LPG	328	13	30	114	47	532
Total	10,020	236.20	1,459	3,505	3,242	18,463

4.2.4 Future Emission Estimation

Emission of different types of pollutant from mobile sources has been estimated till the year 2005 under business–as–usual (BAU) scenario. The estimation has been made according to the procedure explained in chapter III. Here it has been considered that the number of different types of vehicle would have a compounded growth rate (2001 to 2005) as shown in Table 4-21, and there would be no change in the values of average vehicle-kilometer traveled, and the exhaust emission rate (g/km) for each type of the vehicle would be the same as in 1999.

Table 4-21. Estimated number of vehicles in Nakhon Ratchasima municipality.

Types of vehicle	Year				
	2001	2002	2003	2004	2005
Air cond. bus	2,357	2,357	2,357	2,357	2,357
Regular bus	3,599	3,599	3,599	3,599	3,599
Hire pick up	2,331	2,331	2,331	2,331	2,331
Private pick-up	61,975	64,539	67,208	69,988	78,882
Car	27,626	30,878	34,512	38,574	43,114
Truck	7,773	7860	7,948	8,037	8,128
3-wheelers	995	999	1,002	1,005	1,009
Motorcycle	216,490	238,442	262,620	289,250	318,580
Train	47	47	47	47	47

Table 4-22 presents the summary of the projected total quantity of different types of pollutant for the years 2001 to 2005. The details are given Tables B-12 to B-16 in appendix B.

From the results presented in Table 4-22, the emission quantity of CO in 2005 would be up by more than 60% compared to that in the base year 1999. Similarly, the quantities HC and PM_{10} in 2005 would be up by more than 60% and 58%, respectively compared to that in 1999. These results indicate that there is high possibility of worsening the air quality of Nakhon Ratchasima municipality in the years to come.

Table 4-22. Estimated total quantity of pollutants (2001 to 2005).

Years	Pollutants type (tonnes)					
	CO	SO_2	NO_2	HC	PM_{10}	Total
2001	11,715 (54.3%)	256 (1.2%)	1,589 (7.4%)	4,128 (19.1%)	3,876 (18.0%)	21,564 (100%)
2002	12,684 (54.4%)	260 (1.1%)	1,664 (7.1%)	4,487 (19.2%)	4,240 (18.2%)	23,335 (100%)
2003	13,743 (54.4%)	274 (1.1%)	1,743 (6.9%)	4,881 (19.3%)	4,643 (18.3%)	25,284 (100%)
2004	14,906 (54.4%)	279 (1.0%)	1,831 (6.7%)	5,313 (19.4%)	5,086 (18.5%)	27,415 (100%)
2005	16,390 (54.5%)	307 (1.0%)	1,969 (6.5%)	5,838 (19.4%)	5,581 (18.6%)	30,085 (100%)

Source: Results from the study (details in appendix B, Table B-12 to B-16).

4.3 Dose-response Assessment

The usual starting point for an explanation of risk is to point out that there is some risk in everything we do, and since we will all die someday, our lifetime risk of death from all causes is 1.0, or 100 percent. It is easy to gather good data on the causes of death (Masters, 1990).

Such dose-response data could be combined with estimation of likely human exposure to produce overall assessment of risk. The usual staring point for an explanation of risk is to point out that there is some risk in everything. Some gathered data on the causes of disease under surveillance in Nakhon Ratchasima province, Muang district during 1995 to 1999 have been presented in Table 4-23.

From the Table 4-23 one can noticed the number of people who got sickness from different diseases during 1995 to 1999. It is noteworthy that the highest disease is related to respiratory system increasing from 24,717 in 1995 to 52,012 persons in 1999. Respiratory disease can be more or less related emission air pollutants and human exposure.

Table 4-24 shows the percentage of population suffering from respiratory diseases. The percent of population suffering from the respiratory diseases varies from 31 to 35 whose share is all time high.

Table 4-23. Leading diseases under surveillance in Nakhon Ratchasima province, Muang district (1995 to 1999).

Item	Disease Types	1995	1996	1997	1998	1999	Total
1	Diseases related to respiratory system	24,717	31,341	43,252	49,109	52,012	200,431
2	Diseases related to digestive system	10,875	12,360	16,705	17,716	18,085	75,741
3	Certain infections and parasitic	7,404	8,163	9,605	13,101	13,308	51,581
4	Diseases of the musculoskeletal	6,047	6,696	9,669	12,208	13,573	48,193
5	Diseases of the skin	4,269	7,879	9,327	12,155	12,242	45,872
6	Diseases testing by labaratory	5,820	4,855	7,013	5,684	7,649	31,021
7	Diseases of the circulatory system	2,233	2,753	5,811	9,532	9,448	29,777
8	Diseases of the eye and adnexa	1,458	3,285	3,587	5,514	3,789	17,633
9	Endocrine	2,490	2,186	3,501	4,029	4,295	16,501
10	Diseases of the nervous system	2,005	2,298	3,117	2,902	3,811	14,133
11	Others	11,182	8,044	11,345	11,358	17,546	59,475
Total		78,500	89,860	122,932	143,308	155,758	590,358

Source: Nakhon Ratchasima Provincial Public Health Office (1999).

Table 4-24. Percentage of people with respiratory diseases (1995 to 1999).

Year	Ratio of people with respiratory diseases	Percent
1995	24,717 / 78,500	31
1996	31,341 / 89,860	35
1997	43,252 / 122,932	35
1998	49,109 / 143,308	34
1999	52,012 / 155,758	33

4.4 Risk Assessment of Benzene in Ambient Air (road-side)

The US-Environmental Protection Agency (US-EPA) attempts to control exposure of human being to toxic levels that will pose incremental lifetime cancer risks to the most exposed members of the public of 10^{-6} (one additional cancer in one million people) or one-in-one-million (10^{-6}) risks. This is known as the risk goal.

As mentioned in the sub-section 3.3, the chronic daily intake (CDI) at ambient air sampling station A5 was obtained as 0.125 mg/kg-day. After multiplying it by potency factor (see Table A-5), the incremental risk at station A5 was obtained as 3.6×10^{-3} which is higher than the usual goal of risk (10^{-6}). In this regard, risk is much higher in Nakhon Ratchasima municipality than the acceptable level. Therefore, proper mitigation measures for the reduction of emission of benzene concentration from vehicles have to be strictly formulated and implemented.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Nakhon Ratchasima municipality has an approximate area of 37.5 square kilometer and population of about 173,000 in 1999. Due to the increased urbanization and industrial activities, and vehicular traffic have led an increase in fossil fuels' use and have resulted a substantial deterioration of air quality in Nakhon Ratchasima municipality.

In this study, an analysis to know the concentrations of major contaminants (such as CO, C_6H_6, SO_2, NO_2, and PM_{10}) present in the ambient air of the selected locations in Nakhon Ratchasima municipality due to vehicular movements has been done. Ambient air-sampling and analysis were done during the dry season of 1999. The study showed that concentrations of PM_{10} in the ambient air exceeded the existing air quality standard limit of Thailand.

Estimation of the emissions of the key pollutants (such as CO, NO_2, SO_2, HC, and PM_{10}) from transports in Nakhon Ratchasima municipality is also presented in this study using the simple model. Estimation has been done for the year of study (1999) and for the few years to come (2001 to 2005). In the year 1999, emission of CO (54.3%) followed by HC (19%) and PM_{10} (17.8%) had largest share, and thus they were the major pollutants emitted due to the vehicular activities in the municipality.

Under business-as-usual scenario, total emissions of the above pollutants in 2005 would be more than 60% as compared to that in 1999 where CO, HC, and PM_{10} would have large shares as in 1999. Due to increased urbanization and industrialization, air quality of this municipality in the coming years would worsen if proper control measures are not adopted in the days to come.

Preliminary study on risk showed that the incremented risk due to benzene concentration in the ambient air (road side) is higher than the risk goal value. This suggested that there is some risk of benzene in Nakhon Ratchasima municipality.

5.2 Recommendations for Future Study

5.2.1 Improvement In the sampling of ambient air covering more areas is necessary to know better about the air quality situation in the municipality. It is important to measure the concentration of different air pollutants at the entrance and exit of the department store's underground parking. Air sampling and measurement of the emission of the aromatic volatile organic compounds (VOCs) from automobiles along major routes on urban and suburban segments of Nakhon Ratchasima should be done.

5.2.2 Estimations for the total emission of air pollutants from commercial, industrial, and household sectors in Nakhon Ratchasima municipality should be done to know the total emission of air pollutants resulting from the use of fossil fuels.

5.2.3 The emission factors from the vehicles depend on several factors such as vehicles' production year, models, vehicles' age, driving mode, speed, fuel used and so on. For the better estimation of emission source contribution on air quality deterioration, detailed study of emission from vehicles and combustion processes are necessary. In order to develop the emission factors for Nakhon Ratchasima municipality.

5.2.4 As vehicles are one of the major sources of emission of air pollutants in Nakhon Ratchasima municipality, detailed analysis on different policy options for transport system is suggested for the improvement of the air quality in this city.

5.3 Suggestions to Minimize Air Pollution

For minimizing emissions from transportation sector, there are variety of direct and indirect policy and technological measures that can be under taken. Emission control, vehicle volume control, and traffic control are some of the direct measures. While traffic and transport management etc., are some of the indirect measures for minimizing emission from vehicles. Some of them are mention below.

5.3.1 As the air quality of Nakhon Ratchasima municipality appears to be declining, it is an urgent need to establish more stringent emission standards of pollutants (from the sources such as vehicle emissions, building and roads construction, industries, business and residential areas etc.). At the same time, strict enforcement of regulations, and source control strategies for the air quality management. Regular monitoring of air quality is the simplest way to know the up-to date air quality situation.

5.3.2 Implementation of emission control policies, such as improvment of fuel quality, and application of emission control technologies (for details see appendix E) are important to reduce emissions of pollutants from vehicles. Pollution Control Department and Nakhon Ratchasima Municipality Administration Office should work together for its effective implementation.

5.3.3 Government offices and state enterprises that accommodate many people everyday should be relocate outside of the city center to minimize traffic jam and solve car-parking problem.

5.3.4 Transportation system inside fresh food markets in the city should have convenient traffic management and fix enough area for parking. This criterion should be included as part of the regulation for establishment of any such market in future.

5.3.5 Frequent checking of the vehicles for black smokes and other parameters are very important. The concerned authority should take stern action if the emission of the pollutants from any vehicle exceeded the standard limit.

5.3.6 Strict implementation of the traffic law and regulation are also an important aspect to reduce the traffic jam and thus the reduction in the emission of the pollutants from vehicles, safety for passengers and people on the roads would be possible.

5.3.7 Public health department/offices and or pollution control offices should improve their services by giving prior notice information about the air quality situation in the city and make aware about the situation. The service of the existing air quality monitoring system should also be improved further.

5.3.8 Public should be encouraged to utilize their vehicles only on necessities. There should be adequate facility of public transport in many parts of the city.

5.3.9 For the safety and security of the public, there should be proper signs for construction areas, road repair works, and any hazardous sectors. The signs should be equipped with the properly written signal, signal light, or sonic signal for specific risk level from the pollutants for an effective period of time. The commuters should be able to avoid these areas for such a period.

APPENDICES

APPENDIX A

Nakhon Ratchasima Municipality Map
Vehicle Registration Numbers
Data Information for Risk Assessments

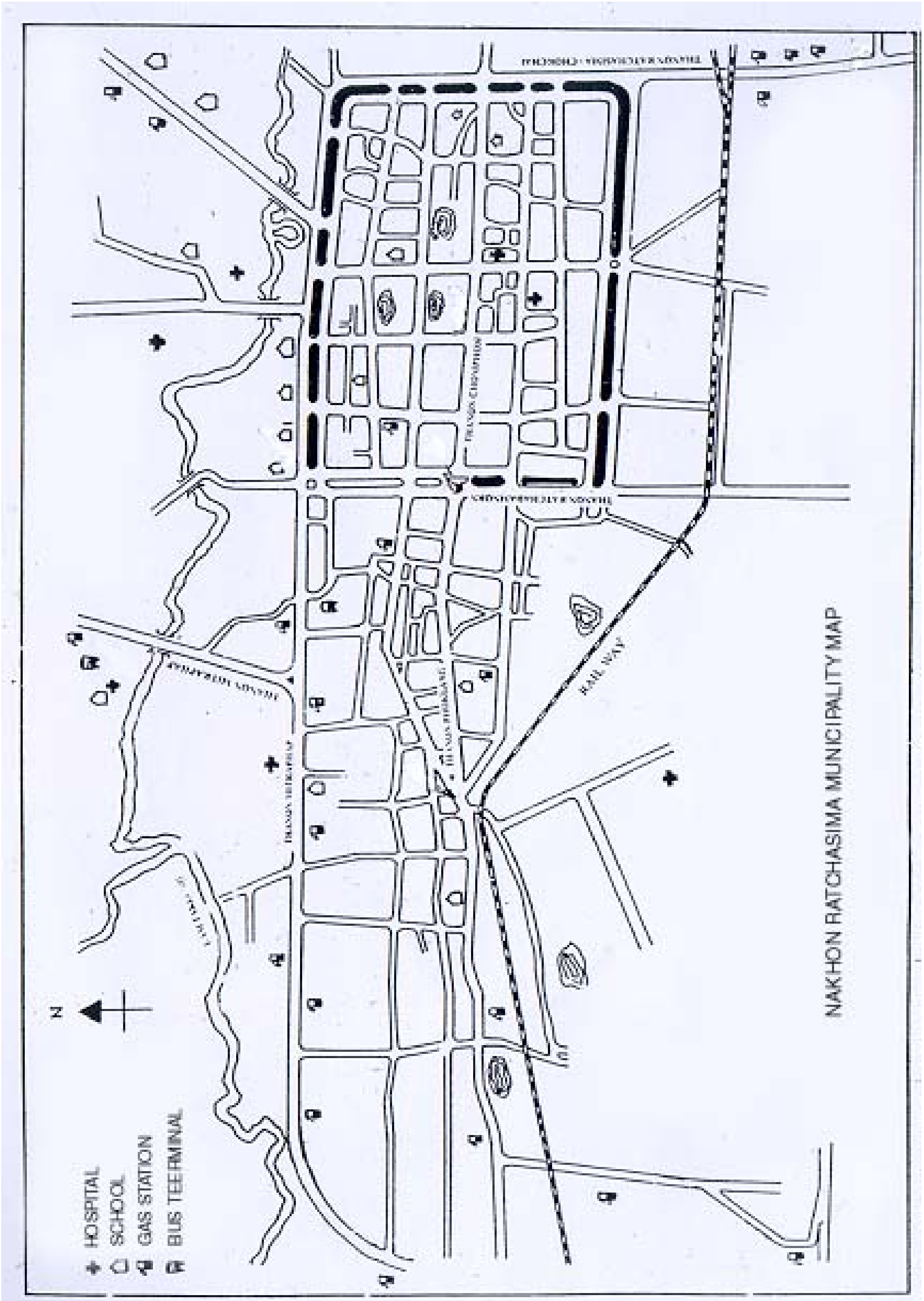

Figure A-1. Nakhon Ratchasima municipality map.

Table A-1. Vehicles registered 1994 to 1999 under Motor Car Act by type.

Type of vehicle	1994	1995	1996	1997	1998	1999
Sedans	12,679	19,113	23,044	21,172	21,616	22,114
Vans and pick-ups	46,466	60,460	65,322	60,075	54,809	56,952
3 – wheelers	973	1,039	1,058	949	989	989
Motorcycles	208,904	273,760	325,815	147,113	148,718	178,463
Other	9,319	11,032	13,694	1.703	1,186	6,466
Total	278,539	365,602	429,131	231,210	227,516	265,182

Source: Nakhon Ratchasima Provincial Transport Office (1999).

Table A-2. Vehicles registered 1994 to 1999 under Land Transport Act by type.

Type of vehicle	1994	1995	1996	1997	1998	1999
Fixed route buses	1,924	2,077	2,274	1,675	1,801	2,141
Non-fixed route buses	49	61	88	169	197	165
Private buses	53	55	63	68	81	68
Small rural buses	181	156	167	40	42	39
Private truck	7,188	8,416	9,664	8,664	6,721	7,601
Total	9,395	10,765	12,256	10,616	8,842	10,014

Source: Nakhon Ratchasima Provincial Transport Office (1999).

Table A-3. Ambient air quality in major cities in Thailand (November 1999).

Location	CO		SO_2		NO_2		PM_{10}	
	Data (ppm)	STD. (ppm)	Data (ppb)	STD. (ppb)	Data (ppb)	STD. (ppb)	Data (μg/m^3)	STD (μg/m^3)
Chieng Mai	a) 2.10 b) 0.50 c) 0.00	30 (1 h)	a) 8.00 b) 0.80 c) 0.00	300 (1 h)	a) 32.00 b) 6.70 c) 0.00	170 (1 h)	a) - b) - c) -	120 (24 h)
Hat Yai	a) 1.70 b) 0.30 c) 0.00		a) 15.00 b) 7.50 c) 0.00		a) - b) – c) -		a) 55.40 b) 38.10 c) 25.80	
Khonkaen	a) 3.70 b) 1.30 c) 0.00		a) - b) – c) -		a) 65.00 b) 23.80 c) 3.00		a) 87.70 b) 68.20 c) 49.80	
Saraburi	a) 8.50 b) 0.40 c) 0.00		a) 11.00 b) 1.20 c) 0.00		a) 45.00 b) 7.60 c) 0.00		a) 33.50 b) 19.80 c) 12.90	
Cholburi	a) 1.40 b) 0.30 c) 0.00		a) 27.00 b) 1.70 c) 0.00		a) 41.00 b) 9.70 c) 0.00		a) 78.30 b) 38.40 c) 18.30	
Bangkok	a) 13.00 b) 0..93 c) 0.00		a) 177 b) 6.15 c) 0.00		a) 141.8 b) 20.57 c) 0.00		a) 224.6 b) 66.45 c) 23.39	
Nakhon Ratchasima	a) 6.51 b) 1.81 c) 0.18		a) 199 b) 118 c) 49.3		a) 4.77 b) 3.25 c) 0.30		a) 359.3 b) 215.4 c) 89.44	

Source: Pollution Control Department (1999).

a)= maximum value, b) = average value, c) = minimum value , (-) = missing data

Table A-4. Fuel consumption in Nakhon Ratchasima municipality, 1999.

Vehicle type	Fuel consumption demand (liter/day)			Fuel consumption supply (liter/day)		
	Diesel	Gasoline	LPG	Diesel	Gasoline	LPG
Air condition bus	9,129	-	-	110,833	87,780	5,667
Regular bus	11,143	-	-			
Hire pick up	2,447	-	-			
3-wheelers	-	-	4,774			
Car	-	7,205	-			
Private pick up	27,405	-	-			
Private truck	4,481	-	-			
Motorcycle	-	11,803	-			
Train	1,313	-	-			
Total	55,918	19,008	4,774	110,833	87,780	5,667

Table A-5. Toxicity data for selected potential carcinogens.

Chemical	Category	Potency factor oral route (mg/kg-day)	Potency factor inhalation route $(mg/kg\text{-}day)^{-1}$
Arsenic	A	1.75	50
Benzene	A	2.9×10^{-2}	2.9×10^{-2}
Benzol(a)pyrene	B2	11.5	6.11
Chloroform	B2	6.1×10^{-3}	8.1×10^{-2}
Methylene chloride	B2	7.5×10^{-3}	1.4×10^{-2}
Trichloroethylene (TCE)	B2	1.1×10^{-2}	1.3×10^{-2}

Source: Masters (1990).

Table A-6. US-EPA exposure factors recommended for risk assessments.

Land use	Exposure pathway	Daily intake	Exposure frequency (days/year)	Exposure duration (yr)	Body weight (kg)
Residential	Ingestion of potable water	2 L (adult) 1 L (child)	350	30	70 (adult) 15 (child)
	Ingestion of soil and dust	200mg (child) 100mg (adult)	350	6 24	15 (child) 70 (adult)
	Inhalation of contaminants	20 m^3 (adult) 10 m^3 (child)	350	30	70
	Ingestion of potable water	1 L	250	25	70
	Ingestion of soil and dust	50 mg	250	25	70
Industrial and commercial	Inhalation of contaminants	20 m^3 (workday)	250	25	70
Agricultural	Consumption of homegrown produce	42 g (fruit) 80 g (veget-able)	350	30	70
Recreational	Consumption of locally caught fish	54 g	350	30	70

Source: United States-Environmental Protection Agency (1991).

APPENDIX B

Emission Factors
Emission Standards
Fuel Consumptions and Emissions

Table B-1. Emission factors for mobile source in Kathmandu (g/km).

Fuel type	Vehicle type	TSP	CO	HC	NO_2	SO_2	Note
Diesel	Truck	3.0	12.0	3.7	13.0	1.75	Based on urban driving conditions (24 km/h)
	Bus	3.0	12.0	3.7	13.0	1.75	
	Mini-bus	1.5	2.25	1.26	13.0	0.39	
	Jeep	0.9	3.10	1.3	1.4	0.38	
	Tractor	0.9	2.25	1.26	1.4	0.39	
Gasoline	Car	0.2	62.0	8.3	2.7	0.13	
	2-wheelers	0.5	24.0	19.0	0.07	0.02	
LPG	Household	0.1	24.0	0.2	5.25	0.02	For stationary source (g/kg)

Source: Shrestha and Malla (1996).

Table B-2. Emission factors for mobile source for average speed of 24 km/h (g/km).

Fuel type	Vehicle type	CO	SO_2	NO_2	HC	PM_{10}
Gasoline	Car	62.00	0.50	2.00	8.30	2.80
	Motorcycle	26.00	0.19	0.20	18.60	5.59
Diesel	Pick-up	1.90	1.55	1.40	0.70	3.11
	Truck	12.40	3.73	20.00	3.70	6.21
	Bus	12.40	3.73	20.00	3.70	6.21
LPG	3-wheeler	4.70	0.50	1.20	4.50	1.85
	Taxi	6.20	0.75	2.00	4.60	2.48

Source: Vitoonchavaritvong (1993).

Table B-3. Thailand emission standard for exhaust emission from new car (diesel engine).

Standard number	Vehicle type	CO	HC + NO_x	NO_x	PM_{10}	Fixed date
Level 3 (1370-2539)	Passenger car limited 6 persons. Passenger car more than 6 persons	2.72 g/km 2.72 - 6.90 g/km	0.97 g/km 0.97 - 1.70 g/km		0.14 g/km 0.14 - 0.25 g/km	1 Jan 1997
Level 3 (1295-2538)	Mini-bus over than 9 persons and 3500 kg weight	4.0 g/kwh	(HC) 1.1 g/kwh	7.0 g/kwh	0.15 g/kwh	1 Jan 1999

Source: Pollution Control Department (1998).

Table B-4. Thailand emission standard for exhaust emission from new motorcycle.

Standard number	Vehicle type	CO	HC	Fixed date
Level 3 (1360-2539)	All	13.0 g/ km	5.0 g/ km	1 Jul 1997

Source: Pollution Control Department (1998).

Table B-5. Ambient air standard of Thailand (1995).

Pollutants	1-h average		8-h average		24-h average		1-month average		1-year average		Method
	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3	ppm	
CO	34.2	30	10.26	9	-	-	-	-	-	-	Non-dispersive infrared detection
NO_2	0.32	0.17	-	-	-	-	-	-	-	-	Chemiluminescence
SO_2	0.78	0.3	-	-	0.3	0.12	-	-	0.1	0.04	UV – fluorescence
PM_{10}	-	-	-	-	0.12	-	-	-	0.05	-	Gravimetric – high volume

Source: Pollution Control Department (1999).

Table B-6. Estimated fuel consumption in Nakhon Ratchasima municipality in 1999.

Vehicle type	Number of vehicle (unit)	Average traveled (km/yr-unit)	Fuel efficiency (km/L)	Fuel type	Average fuel consumption (L/yr-unit)
Air cond. bus	2,357	4,709	3.33	Diesel	1,414
Regular bus	3,599	3,729	3.30	Diesel	1,130
Hire pick up	2,331	3,257	8.50	Diesel	383
Private pickup	56,952	5,110	10.0	Diesel	511
Car	22,114	4,380	12.0	Gasoline	365
Private truck	7,601	3,285	4.5	Diesel	730
3–wheelers	989	25,549	14.5	LPG	1,762
Motorcycle	178,463	2,920	31.5	Gasoline	92
Train	47	2,549	0.25	Diesel	10,197

Table B-7. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 1994 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	1,690	93	343	417	61	2,604
Truck	283	41	307	87	147	865
Train	1	0.2	2	0.4	1	4
Car	151	7	150	54	8	370
Motorcycle	7,930	12	122	3,050	3,410	14,524
3–wheelers	323	13	30	112	46	524
Total	10,672	208	1,272	3,811	3,710	19,673
%	54.25	1.06	6.47	19.37	18.86	100

Table B-8. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 1995 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2,184	120	444	538	64	3,365
Truck	332	48	359	102	83	1,013
Train	1	0.2	2	0.4	0.2	5
Car	228	147	226	81	12	694
Motorcycle	10,391	16	160	3,997	4,469	19,033
3–wheelers	345	13	32	119	49	558
Total	13,775	386	1,541	4,929	4,819	25,450
%	54.13	1.52	6.06	19.37	18.94	100

Table B-9. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 1996 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2,355	130	478	580	85	3,628
Truck	381	56	413	117	197	1,164
Train	1	0.2	2	0.4	1	4
Car	275	177	273	98	14	837
Motorcycle	12,368	19	190	4,757	5,318	22,652
3–wheelers	351	14	32	122	50	569
Total	16,025	438	1,706	5,765	5,702	29,636
%	54.07	1.48	5.76	19.45	19.24	100

Table B-10. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 1997 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2,170	120	441	535	79	3,345
Truck	342	50	370	105	177	1,044
Train	1	0.2	2	0.4	1	4
Car	252	12	250	90	13	617
Motorcycle	5,584	8.6	86	2,148	2,401	10,228
3–wheelers	315	12	29	109	45	510
Total	8,958	245	1,496	3,078	2,753	16,530
%	54.19	1.48	9.05	18.62	16.65	100

Table B-11. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 1998 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	1,985	112	403	489	58	3,061
Truck	265	39	287	82	137	810
Train	1	0.2	2	0.4	1	4
Car	263	12	262	92	13	642
Motorcycle	5,645	9	87	2,171	2,427	10,339
3–wheelers	328	13	30	114	47	532
Total	8,781	227	1,389	3,039	2,734	16,170
%	54.31	1.41	8.59	18.79	16.91	100

Table B-12. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 2001 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2,237	127	454	551	81	3,450
Truck	306	45	332	94	159	936
Train	1	0.2	2	0.4	0.7	4
Car	329	16	326	117	17	805
Motorcycle	8,218	12.6	126	3,161	3,534	15,052
3–wheelers	330	13	31	114	47	535
Total	11,715	256	1,589	4,128	3,876	21,564
%	54.33	1.19	7.37	19.14	17.97	100

Table B-13. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 2002 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2328	128	473	574	84	3,587
Truck	310	45	336	96	160	947
Train	1	0.2	2	0.4	0.7	4
Car	368	18	365	131	19	901
Motorcycle	9,051	12.6	139	3,481	3,892	16,576
3–wheelers	332	13	31	114	47	537
Total	12,684	260	1,664	4,487	4,240	23,335
%	54.36	1.11	7.13	19.23	18.17	100

Table B-14. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 2003 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2,422	137	492	597	88	3,736
Truck	313	46	339	97	162	957
Train	1	0.2	2	0.4	1	5
Car	411	20	408	147	21	1,007
Motorcycle	9,969	15.3	153	3,834	4,287	18,258
3–wheelers	333	13	31	115	47	539
Total	13,743	274	1,743	4,881	4,643	25,284
%	54.35	1.08	6.89	19.31	18.37	100

Table B-15. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 2004 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2520	139	512	621	91	3,883
Truck	317	46	343	98	164	968
Train	1	0.2	2	0.4	1	5
Car	460	296	456	164	24	1,126
Motorcycle	10,980	16.9	169	4,223	4,721	20,110
3–wheelers	334	13	31	116	48	542
Total	14,906	279	1,831	5,313	5,086	27,415
%	54.37	1.02	6.68	19.38	18.55	100

Table B-16. Estimated total emission of selected pollutants in transportation sector in Nakhon Ratchasima municipality in 2005 (tonnes).

Vehicle type	CO	SO_2	NO_2	HC	PM_{10}	Total
Bus	294	42	318	91	37	782
pick up	2,833	160	575	698	103	4,158
Truck	320	47	347	99	166	979
Train	1	0.2	2	0.4	1	5
Car	514	26	510	183	26	1,259
Motorcycle	12,093	18.6	186	4,651	5,200	22,149
3–wheelers	335	13	31	116	48	543
Total	16,390	307	1,969	5,838	5,581	30,085
%	54.16	1.03	6.59	19.54	18.68	100

Table B-17. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 1994.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	46,466	6.9	1,638
Car	4,380	12,679	2.72	151
Truck	3,285	7,188	12.0	283
3–wheelers	25,549	973	13.0	323
Motorcycle	2,920	208,904	13.0	7,930
Train	2,549	47	12.0	1

Table B-18. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 1994.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. Bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	46,466	0.39	90
Car	4,380	12,679	0.13	7
Truck	3,285	7,188	1.75	41
3–wheelers	25,549	973	0.50	13
Motorcycle	2,920	208,904	0.02	12
Train	2,549	47	1.75	0.2

Table B-19. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 1994.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	46,466	1.4	332
Car	4,380	12,679	2.7	150
Truck	3,285	7,188	13.0	307
3–wheelers	25,549	973	1.2	30
Motorcycle	2,920	208,904	0.2	122
Train	2,549	47	13.0	2

Table B-20. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 1994.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	46,466	1.7	404
Car	4,380	12,679	0.97	54
Truck	3,285	7,188	3.7	87
3–wheelers	25,549	973	4.5	112
Motorcycle	2,920	208,904	5.0	3,050
Train	2,549	47	3.7	0.4

Table B-21. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 1994.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	46,466	0.25	59
Car	4,380	12,679	0.14	8
Truck	3,285	7,188	6.21	147
3–wheelers	25,549	973	1.85	46
Motorcycle	2,920	208,904	5.59	3,410
Train	2,549	47	6.21	1

Table B-22. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 1995.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	60,460	6.9	2,132
Car	4,380	19,113	2.72	228
Truck	3,285	8,416	12.0	332
3–wheelers	25,549	1,039	13.0	345
Motorcycle	2,920	273,760	13.0	10,391
Train	2,549	47	12.0	1

Table B-23. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 1995.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	60,460	0.39	117
Car	4,380	19,113	1.75	147
Truck	3,285	8,416	1.75	48
3–wheelers	25,549	1,039	0.5	13
Motorcycle	2,920	273,760	0.02	16
Train	2,549	47	1.75	0.2

Table B-24. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 1995.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	60,460	1.4	433
Car	4,380	19,113	2.7	226
Truck	3,285	8,416	13.0	359
3–wheelers	25,549	1,039	1.2	32
Motorcycle	2,920	273,760	0.20	160
Train	2,549	47	13.0	2

Table B-25. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 1995.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	60,460	1.7	525
Car	4,380	19,113	0.97	81
Truck	3,285	8,416	3.7	102
3–wheelers	25,549	1,039	4.5	119
Motorcycle	2,920	273,760	5.0	3,997
Train	2,549	47	3.7	0.4

Table B-26. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 1995.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	60,460	0.25	77
Car	4,380	19,113	0.14	12
Truck	3,285	8,416	6.21	172
3–wheelers	25,549	1,039	1.85	49
Motorcycle	2,920	273,760	5.59	4,469
Train	2,549	47	6.21	1

Table B-27. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 1996.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	65,322	6.9	2,303
Car	4,380	23,044	2.72	275
Truck	3,285	9,664	12.0	381
3–wheelers	25,549	1,058	13.0	351
Motorcycle	2,920	325,815	13.0	12,368
Train	2,549	47	12.0	1

Table B-28. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 1996.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	65,322	0.39	127
Car	4,380	23,044	1.75	177
Truck	3,285	9,664	1.75	56
3–wheelers	25,549	1,058	0.50	14
Motorcycle	2,920	325,815	0.02	19
Train	2,549	47	1.75	0.2

Table B-29. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 1996.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	65,322	1.4	467
Car	4,380	23,044	2.7	273
Truck	3,285	9,664	13.0	413
3–wheelers	25,549	1,058	1.2	32
Motorcycle	2,920	325,815	0.2	190
Train	2,549	47	13.0	2

Table B-30. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 1996.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	65,322	1.7	567
Car	4,380	23,044	0.97	98
Truck	3,285	9,664	3.7	117
3–wheelers	25,549	1,058	4.5	122
Motorcycle	2,920	325,815	5.0	4,757
Train	2,549	47	3.7	0.4

Table B-31. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 1996.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	65,322	0.25	83
Car	4,380	23,044	0.14	14
Truck	3,285	9,664	6.21	197
3–wheelers	25,549	1,058	1.85	50
Motorcycle	2,920	325,815	5.59	5,318
Train	2,549	47	6.21	1

Table B-32. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 1997.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	60,075	6.9	2,118
Car	4,380	21,172	2.72	252
Truck	3,285	8,664	12.0	342
3–wheelers	25,549	949	13.0	315
Motorcycle	2,920	147,113	13.0	5,584
Train	2,549	47	12.0	1

Table B-33. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 1997.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	60,075	0.39	117
Car	4,380	21,172	0.13	12
Truck	3,285	8,664	1.75	50
3–wheelers	25,549	949	0.5	12
Motorcycle	2,920	147,113	0.02	8.6
Train	2,549	47	1.75	0.2

Table B-34. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 1997.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	60,075	1.4	430
Car	4,380	21,172	2.7	250
Truck	3,285	8,664	13.0	370
3–wheelers	25,549	949	1.2	29
Motorcycle	2,920	147,113	0.2	86
Train	2,549	47	13.0	2

Table B-35. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 1997.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	60,075	1.7	522
Car	4,380	21,172	0.97	90
Truck	3,285	8,664	3.7	105
3–wheelers	25,549	949	4.5	109
Motorcycle	2,920	147,113	5.0	2,148
Train	2,549	47	3.7	0.4

Table B-36. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 1997.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	60,075	0.25	77
Car	4,380	21,172	0.14	13
Truck	3,285	8,664	6.21	177
3–wheelers	25,549	949	1.85	45
Motorcycle	2,920	147,113	5.59	2,401
Train	2,549	47	6.21	1

Table B-37. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 1998.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	54,809	6.9	1,933
Car	4,380	21,616	2.72	258
Truck	3,285	6,721	12.0	265
3–wheelers	25,549	989	13.0	328
Motorcycle	2,920	148,718	13.0	5,645
Train	2,549	47	12.0	1

Table B-38. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 1998.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	54,809	0.39	109
Car	4,380	21,616	0.13	12
Truck	3,285	6,721	1.75	39
3–wheelers	25,549	989	0.5	13
Motorcycle	2,920	148,718	0.02	9
Train	2,549	47	1.75	0.2

Table B-39. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 1998.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	54,809	1.4	392
Car	4,380	21,616	2.7	256
Truck	3,285	6,721	13.0	287
3–wheelers	25,549	989	1.2	30
Motorcycle	2,920	148,718	0.2	87
Train	2,549	47	13.0	2

Table B-40. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 1998.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	54,809	1.7	476
Car	4,380	21,616	0.97	92
Truck	3,285	6,721	3.7	82
3–wheelers	25,549	989	4.5	114
Motorcycle	2,920	148,718	5.0	2,171
Train	2,549	47	3.7	0.4

Table B-41. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 1998.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	54,809	0.25	70
Car	4,380	21,616	0.14	13
Truck	3,285	6,721	6.21	137
3–wheelers	25,549	989	1.85	47
Motorcycle	2,920	148,718	5.59	2,427
Train	2,549	47	6.21	1

Table B-42. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 1999.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	56,952	6.9	2,008
Car	4,380	22,114	2.72	263
Truck	3,285	7,601	12.0	300
3–wheelers	25,549	989	13.0	328
Motorcycle	2,920	178,463	13.0	6,774
Train	2,549	47	12.0	1

Table B-43. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 1999.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	56,952	0.39	111
Car	4,380	22,114	0.13	13
Truck	3,285	7,601	1.75	44
3–wheelers	25,549	989	0.5	13
Motorcycle	2,920	178,463	0.02	10
Train	2,549	47	1.75	0.2

Table B-44. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 1999.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	56,952	1.4	407
Car	4,380	22,114	2.7	262
Truck	3,285	7,601	13.0	325
3–wheelers	25,549	989	1.2	30
Motorcycle	2,920	178,463	0.2	104
Train	2,549	47	13.0	2

Table B-45. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 1999.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	56,952	1.7	495
Car	4,380	22,114	0.97	94
Truck	3,285	7,601	3.7	92
3–wheelers	25,549	989	4.5	114
Motorcycle	2,920	178,463	5.0	2,606
Train	2,549	47	3.7	0.4

Table B-46. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 1999.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	56,952	0.25	73
Car	4,380	22,114	0.14	14
Truck	3,285	7,601	6.21	155
3–wheelers	25,549	989	1.85	47
Motorcycle	2,920	178,463	5.59	2,913
Train	2,549	47	6.21	1

Table B-47. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 2001.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	61,975	6.9	2,185
Car	4,380	27,626	2.72	329
Truck	3,285	7,773	12.0	306
3–wheelers	25,549	995	13.0	330
Motorcycle	2,920	216,440	13.0	8,218
Train	2,549	47	12.0	1

Table B-48. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 2001.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	61,975	0.39	124
Car	4,380	27,626	0.13	16
Truck	3,285	7,773	1.75	45
3–wheelers	25,549	995	0.5	13
Motorcycle	2,920	216,490	0.02	12.6
Train	2,549	47	1.75	0.2

Table B-49. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 2001.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	61,975	1.4	443
Car	4,380	27,626	2.7	326
Truck	3,285	7,773	13.0	332
3–wheelers	25,549	995	1.2	31
Motorcycle	2,920	216,490	0.2	126
Train	2,549	47	13.0	2

Table B-50. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 2001.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	61,975	1.7	538
Car	4,380	27,626	0.97	117
Truck	3,285	7,773	3.7	94
3–wheelers	25,549	995	4.5	114
Motorcycle	2,920	216,490	5.0	3,161
Train	2,549	47	3.7	0.4

Table B-51. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 2001.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	61,975	0.25	79
Car	4,380	27,626	0.14	17
Truck	3,285	7,773	6.21	159
3–wheelers	25,549	995	1.85	47
Motorcycle	2,920	216,490	5.59	3,534
Train	2,549	47	6.21	0.7

Table B-52. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 2002.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	64,539	6.9	2,276
Car	4,380	30,878	2.72	368
Truck	3,285	7,860	12.0	310
3–wheelers	25,549	999	13.0	332
Motorcycle	2,920	238,442	13.0	9,051
Train	2,549	47	12.0	1

Table B-53. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 2002.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	64,539	0.39	125
Car	4,380	30,878	0.13	18
Truck	3,285	7,860	1.75	45
3–wheelers	25,549	999	0.5	13
Motorcycle	2,920	238,442	0.02	14
Train	2,549	47	1.75	0.2

Table B-54. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 2002.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	64,539	1.4	462
Car	4,380	30,878	2.7	365
Truck	3,285	7,860	13.0	336
3–wheelers	25,549	999	1.2	31
Motorcycle	2,920	238,442	0.2	139
Train	2,549	47	13.0	2

Table B-55. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 2002.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	64,539	1.7	561
Car	4,380	30,878	0.97	131
Truck	3,285	7,860	3.7	96
3–wheelers	25,549	999	4.5	114
Motorcycle	2,920	238,442	5.0	3,481
Train	2,549	47	3.7	0.4

Table B-56. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 2002.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	64,539	0.25	82
Car	4,380	30,878	0.14	19
Truck	3,285	7,860	6.21	160
3–wheelers	25,549	999	1.85	47
Motorcycle	2,920	238,442	5.59	3,892
Train	2,549	47	6.21	0.7

Table B-57. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 2003.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	67,208	6.9	2,370
Car	4,380	34,512	2.72	411
Truck	3,285	7,948	12.0	313
3–wheelers	25,549	1,002	13.0	333
Motorcycle	2,920	262,620	13.0	9,969
Train	2,549	47	12.0	1

Table B-58. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 2003.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	67,208	0.39	134
Car	4,380	34,512	0.13	20
Truck	3,285	7,948	1.75	46
3–wheelers	25,549	1,002	0.5	13
Motorcycle	2,920	262,620	0.02	15.3
Train	2,549	47	1.75	0.2

Table B-59. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 2003.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	67,208	1.4	481
Car	4,380	34,512	2.7	408
Truck	3,285	7,948	13.0	339
3–wheelers	25,549	1,002	1.2	31
Motorcycle	2,920	262,620	0.2	153
Train	2,549	47	13.0	2

Table B-60. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 2003.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	67,208	1.7	584
Car	4,380	34,512	0.97	147
Truck	3,285	7,948	3.7	97
3–wheelers	25,549	1,002	4.5	115
Motorcycle	2,920	262,620	5.0	3,834
Train	2,549	47	3.7	0.4

Table B-61. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 2003.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	67,208	0.25	86
Car	4,380	34,512	0.14	21
Truck	3,285	7,948	6.21	162
3–wheelers	25,549	1,002	1.85	47
Motorcycle	2,920	262,620	5.59	4,287
Train	2,549	47	6.21	1

Table B-62. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 2004.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	69,988	6.9	2,468
Car	4,380	38,574	2.72	460
Truck	3,285	8,037	12.0	317
3–wheelers	25,549	1,005	13.0	334
Motorcycle	2,920	289,250	13.0	10,980
Train	2,549	47	12.0	1

Table B-63. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 2004.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	69,988	0.39	136
Car	4,380	38,574	0.13	22
Truck	3,285	8,037	1.75	46
3–wheelers	25,549	1,005	0.5	13
Motorcycle	2,920	289,250	0.02	17
Train	2,549	47	1.75	0.2

Table B-64. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 2004.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	69,988	1.4	501
Car	4,380	38,574	2.7	456
Truck	3,285	8,037	13.0	343
3–wheelers	25,549	1,005	1.2	31
Motorcycle	2,920	289,250	0.2	169
Train	2,549	47	13.0	2

Table B-65. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 2004.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	69,988	1.7	608
Car	4,380	38,574	0.97	164
Truck	3,285	8,037	3.7	98
3–wheelers	25,549	1,005	4.5	116
Motorcycle	2,920	289,250	5.0	4,223
Train	2,549	47	3.7	0.4

Table B-66. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 2004.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	69,988	0.25	89
Car	4,380	38,574	0.14	24
Truck	3,285	8,037	6.21	164
3–wheelers	25,549	1,005	1.85	48
Motorcycle	2,920	289,250	5.59	4,721
Train	2,549	47	6.21	1

Table B-67. Estimated exhaust emission for carbon monoxide (CO) in Nakhon Ratchasima municipality in 2005.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	12.0	133
Regular bus	3,729	3,599	12.0	161
Hire pick up	3,257	2,331	6.9	52
Private pick up	5,110	78,882	6.9	2,781
Car	4,380	43,114	2.72	514
Truck	3,285	8,128	12.0	320
3–wheelers	25,549	1,009	13.0	335
Motorcycle	2,920	318,580	13.0	12,093
Train	2,549	47	12.0	1

Table B-68. Estimated exhaust emission for sulfur dioxide (SO_2) in Nakhon Ratchasima municipality in 2005.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.75	19
Regular bus	3,729	3,599	1.75	23
Hire pick up	3,257	2,331	0.39	3
Private pick up	5,110	78,882	0.39	157
Car	4,380	43,114	0.13	26
Truck	3,285	8,128	1.75	47
3–wheelers	25,549	1,009	0.5	13
Motorcycle	2,920	318,580	0.02	18.6
Train	2,549	47	1.75	0.2

Table B-69. Estimated exhaust emission for nitrogen dioxide (NO_2) in Nakhon Ratchasima municipality in 2005.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	13.0	144
Regular bus	3,729	3,599	13.0	174
Hire pick up	3,257	2,331	1.4	11
Private pick up	5,110	78,882	1.4	564
Car	4,380	43,114	2.7	510
Truck	3,285	8,128	13.0	347
3–wheelers	25,549	1,009	1.2	31
Motorcycle	2,920	318,580	0.2	186
Train	2,549	47	13.0	2

Table B-70. Estimated exhaust emission for hydrocarbon (HC) in Nakhon Ratchasima municipality in 2005.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	3.7	41
Regular bus	3,729	3,599	3.7	50
Hire pick up	3,257	2,331	1.7	13
Private pick up	5,110	78,882	1.7	685
Car	4,380	43,114	0.97	183
Truck	3,285	8,128	3.7	99
3–wheelers	25,549	1,009	4.5	116
Motorcycle	2,920	318,580	5.0	4,651
Train	2,549	47	3.7	0.4

Table B-71. Estimated exhaust emission for PM_{10} in Nakhon Ratchasima municipality in 2005.

Vehicle type	$vkm_i(t)$ Average traveled (km/yr-unit)	$N_i(t)$ Number of vehicle (unit)	EF_{ij} Exhaust emission factor (g/km)	$M_{ij}(t)$ Emission (tonnes)
Air cond. bus	4,709	2,357	1.5	17
Regular bus	3,729	3,599	1.5	20
Hire pick up	3,257	2,331	0.25	2
Private pick up	5,110	78,882	0.25	101
Car	4,380	43,114	0.14	26
Truck	3,285	8,128	6.21	166
3–wheelers	25,549	1,009	1.85	48
Motorcycle	2,920	318,580	5.59	5,200
Train	2,549	47	6.21	1

APPENDIX C

Data Information in Transportation Sector

Table C-1. Train transport pass through Nakhon Ratchasima municipality.

Train type	Number of trains (unit/day)	Distance (km/day)	Time rate (min/day)	Fuel rate		Fuel consumption (L/day)
				km/L	min/L	
Diesel train	17	93	220	4.5	5.88	37
Air cond. train	8	64	96	4.5	5.88	16
Express train	12	90	140	0.2	0.27	520
Cargo	10	80	200	0.2	0.27	740
Total	47	327	656			1,313

Source: Champathong (2000).

Table C-2. Number of fixed route buses pass through Nakhon Ratchasima municipality.

Vehicle type	Number of vehicle (unit/day)	Distance (km/day)	Fuel rate (km/L)	Fuel type	Fuel consumption (L/day)
Air cond. buse	1,624	22,092	3.33	Diesel	6,634.23
Regular buse	306	4,187	3.0	Diesel	1,395.67
Total	1,930	26,279			8,029.90

Source: Nakhon Ratchasima Provincial Transport Office (1998).

Table C-3. Number of fixed route buses start from Nakhon Ratchasima municipality to outside.

Vehicle type	Number of vehicle (unit/day)	Distance (km/day)	Fuel rate (km/L)	Fuel type	Fuel consumption (L/day)
Air cond. buse	278	1,946	3.33	Diesel	584.38
Regular buse	1,792	12,502	3.30	Diesel	4,167.33
Hire pick-up	508	3,556	7.0	Diesel	508.00
Total	2,578	18,004			5,259.71

Source: Nakon Ratchasima Provincial Transport Office (1998).

Table C-4. Number of fixed route buses traveling inside Nakhon Ratchasima municipality.

Vehicle type	Number of vehicle (unit/day)	Distance (km/day)	Fuel rate (km/L)	Fuel type	Fuel consumption (L/day)
Air cond. buses	455	6,362	3.33	Diesel	1,910.51
Regular buses	1,501	20,086	3.30	Diesel	5,738.86
Hire pick-ups	1,823	17,244	7.00	Diesel	2,463.43
Total	3,779	43,692			10,112.80

Source: Nakon Ratchasima Provincial Transport Office (1998).

Table C-5. Fixed route buses passing through Nakhon Ratchasima municipality area.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
2	- Air cond. - Regular	4	BKK – Kantralux	22 4	11 11	242 44
	- Air cond. - Regular	5	BKK – Sri Cheingmai	24 8	14 14	336 112
	- Air cond. - Regular	7	BKK - Chongmek	16 4	14 14	224 56
	- Air cond. - Regular	20	BKK - Khonkean	158 12	14 14	2,212 168
	- Air cond. - Regular	21	BKK - NKR	464 38	14 14	6,496 532
	- Air cond. - Regular	22	BKK – Udorn	70 18	14 14	980 252
	- Air cond. - Regular	23	BKK - Nongkai	30 12	14 14	420 168
	- Air cond. - Regular	24	BKK - Dorntal	50 24	14 14	700 336
	- Air cond. - Regular	25	BKK – Ubol	60 4	11 11	660 44
	- Air cond. - Regular	26	BKK-Na khon panom	30 6	14 14	420 84
	- Air cond. - Regular	27	BKK – Ranu nakhon	42 8	14 14	588 112
	- Air cond. - Regular	30	BKK - Karasin	158 12	14 14	2,212 168
	- Air cond. - Regular	33	BKK – Ban phang	24 6	14 14	336 84
	- Air cond. - Regular	34	BKK – Sahatsakan	10 4	14 14	140 56
	- Air-condition	79	BKK - Kum pawa pee	6	14	84
	- Air cond. - Regular	86	BKK - Kutchum	18 4	14 14	252 56
	- Air-condition	97	BKK – Pungkhon	10	14	140
	- Air cond. - Regular	927	BKK - Mukdaharn	36 10	14 14	504 140
	- Air cond. - Regular	928	BKK – Kasertwisai	16 4	14 14	224 56
	- Air cond. - Regular	929	BKK - Kemarat	24 8	14 14	336 112

Table C-5 (cont'd). Fixed route buses passing through Nakhon Ratchasima municipality area.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
2	- Air cond. - Regular	930	BKK-Nakorn pha-nom	16 4	14 14	224 56
	- Air cond. - Regular	931	BKK – Ubol	10 4	14 14	140 56
	- Air cond. - Regular	932	BKK - Maha sarakam	20 4	14 14	280 56
	- Air cond. - Regular	933	BKK – Sri chaing Mai	20 4	14 14	280 56
	- Air cond. - Regular	934	BKK – Phanompai	28 10	14 14	392 140
	- Air cond. - Regular	935	BKK– Suwan naphum	28 8	14 14	392 112
	- Air cond. - Regular	936	BKK – Burirum	16 4	11 11	176 44
	- Air cond. - Regular	937	BKK - Surin	20 4	11 11	220 44
	- Air cond. - Regular	938	BKK – Loei	20 4	14 14	280 56
	- Air condition	939	BKK–Payak phum Pisai	18	14	252
	- Regular	940	BKK - Srisaket	8	11	88
	- Air cond. - Regular	941	BKK – Panompai	14 4	14 14	196 56
	- Air cond. - Regular	942	BKK – Srisaket	16 4	11 11	176 44
	- Air cond. - Regular	943	BKK – BungKarn	4 4	14 14	56 56
	- Air cond. - Regular	944	BKK – Ubol	24 8	14 14	336 112
	- Regular	946	BKK – Mukdaharn	4	14	56
	- Air cond. - Regular	947	BKK – Ubol	18 6	11 11	198 66
	- Air cond. - Regular	955	BKK – Khongjiem	12 4	11 11	132 44
	- Air cond. - Regular	968	BKK – Yasothon	16 4	14 14	224 56
	- Air cond. - Regular	588	Ubol – Rayong	14 6	11 11	154 66

Table C-5 (cont'd). Fixed route buses passing through Nakhon Ratchasima municipality area.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
2	- Air cond. - Regular	589	Ubol – Pattaya	18 8	11 11	198 88
	- Air cond. - Regular	590	Nongkai – Rayong	20 18	14 14	280 252
Total	- Air cond. - Regular			1,624 306		22,092 4,184

Source: Nakhon Ratchasima Provincial Transport Office (1998).

Table C-6. Fixed route buses starting from Nakhon Ratchasima municipality area.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
3	- Air cond. - Regular	108	NKR – Lobburi	18 14	7 7	126 98
	- Regular	121	NKR–Na korn Sawan	8	7	56
	- Air cond. - Regular	141	NKR – Petchaboon	6 32	7 7	42 224
	- Air cond. - Regular	204	NKR–Chaiya phoom	20 48	7 7	140 336
	- Regular	208	NKR–Bum netnarong	10	7	70
	- Air cond. - Regular	210	NKR – Khonkaen	6 6	7 7	42 42
	- Air cond. - Regular	211	NKR – Udorn	6 36	7 7	42 252
	- Air cond. - Regular	262	NKR – Sri Cheingmai	4 10	7 7	28 70
	- Air cond. - Regular	265	NKR – Cholburi	36 22	7 7	252 154
	- Air cond. - Regular	267	NKR – Rayong	58 26	7 7	406 182
	- Regular	273	NKR – Burirum	6	7	42
	- Air cond. - Regular	274	NKR – Surin	10 82	7 7	70 574
	- Air cond. - Regular	285	NKR – UBR	8 6	7 7	56 42

Table C-6 (cont'd). Fixed route buses starting from Nakhon Ratchasima municipality area.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
3	- Air cond. - Regular	340	NKR – Chantaburi	36 22	7 7	252 154
	- Regular	502	NKR – Yasothorn	30	7	210
	- Regular	517	NKR – Lamnarai	8	7	56
	- Regular - Hipickup	265	NKR – Dankhuntod	6 8	7 7	42 56
	- Air cond. - Regular	563	NKR – Surin	6 122	7 7	42 854
	- Air cond. - Regular	570	NKR – Banphang	4 8	7 7	28 56
	- Regular	571	NKR – Sarakaew	60	7	420
	- Air cond. - Regular	572	NKR – Pitsanulok	4 6	7 7	28 42
	- Air cond. - Regular	579	NKR – Lahansai	6 20	7 7	42 140
	- Air cond. - Regular	635	NKR – Cheing Mai	20 6	7 7	140 42
	- Air condition	651	NKR – Maesai	12	7	84
	- Air condition	808	NKR – Cheingkhan	12	7	84
4	- Regular	1301	NKR – Soongnern	24	7	168
	- Air cond. - Regular	1302	NKR – Pakchong	6 50	7 7	42 350
	- Regular	1303	NKR –Puk thongchai	104	7	728
	- Regular	1305	NKR – Chumpung	72	7	504
	- Regular - Hirepickup	1306	NKR – Nonthai	28 50	7 7	196 350
	- Regular - Hirepickup	1307	NKR – Chokchai	106 60	7 7	742 420
	- Regular	1308	NKR-Buayai	20	7	140
	- Regular	1310	NKR-Srique	98	7	686

Table C-6 (cont'd). Fixed route buses starting from Nakhon Ratchasima municipality area.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
4	-Regular	1313	NKR-Kutpakeng	54	7	378
	-Regular/ -Hirepickup	4129	NKR-Km10	64	7	448
	-Regular/ -Hirepickup	4131	NKR – Soongnern	108	7	756
	-Hire pick ups	4139	NKR – Ban Phow	48	7	336
	-Hire pick ups	4140	NKR – Nongngu	6	7	42
	-Regular / -Hirepickup	4142	NKR – Ban Bing	14	7	98
	-Regular	4144	NKR – Ban Samrit	96	7	672
	-Regular / -Hirepickup	4197	NKR – Ban Romfarkuru	12 48	7 7	84 336
	-Regular / -Hirepickup	4198	NKR – Ban Tatabag	16	7	112
	-Regular / -Hirepickup	4234	NKR-Ban Tachang	60 30	7 7	420 210
	-Regular / -Hirepickup	4287	NKR- Ban Donkating	80	7	560
	-Hire pick ups	4360	NKR-Ban Tapchang	20	7	140
	-Regular / -Hirepickup	4391	NKR-Dankuntod	52	7	364
	-Regular / -Hirepickup	4404	NKR-Ban Nongwang	8 24	7 7	56 168
	-Regular or two roll	4415	NKR –Ban Nongprado	34	7	238
	-Two roll pick ups	4416	NKR – Ban Pundung	18	7	126
	-Two roll pick ups	4424	NKR – Ban Huasara	56	7	392
	-Two roll pick ups	4425	NKR – Ban Nongpluang	60	7	420
	-Regular / -Hirepickup	4426	NKR – Ban Natom	80	7	560
	-Regular	4448	NKR–Kang snamnang	20	7	140

Table C-6 (cont'd). Fixed route buses starting from Nakhon Ratchasima municipality area.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
4	-Regular	4449	NKR – Ban Pacome	8	7	56
	-Regular / -Hirepickup	4453	NKR-Ban Chong-eu	46	7	322
	-Regular	4460	NKR- Ban Nongbong	24	7	168
	-Regular	1313	NKR-Kutpakeng	54	7	378
	-Regular/ -Hirepickup	4129	NKR-Km10	64	7	448
	-Regular/ -Hirepickup	4131	NKR – Soongnern	108	7	756
Total	-Air -Regular -Hirepickup			278 1,792 508		1,946 12,502 3,556

Source: Nakhon Ratchasima Provincial Transport Office (1998).

Table C-7. Fixed rough buses and hire pick-up inside Nakhon Ratchasima municipality.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
2	-Regular -Hirepickup -Air Bus	1	Ratcha mong kol – SUT.	160 300 120	14 14 14	2,240 4,200 1,680
	-Regular -Air Bus	2	C.Tech.-KR princ.	90 60	14 8	1,260 480
	-Regular	3	Makamtua-Watsakaew	50	16	800
	-Regular	4	Horse racing -Boonlua	246	14	3,444
	-Regular	5	Indust.Zone -Polytech.	158	16	2,528
	-Regular	6	Jawho-C.Tech.	300	15	4,500
	-Hire pick ups	7	Pradok-Huatalay	658	7	4,606

Table C-7 (cont'd). Fixed rough buses and hire pick-up inside Nakhon Ratchasima municipality.

Group	Types	Line No.	Line name	No. of vehicle unit/day	Distance inside NKRM km/unit	Total distance inside NKRM km/day
2	-Hire pick ups	8	Watsarawan-Huatanon	398	9	3,582
	-Regular -Hirepickup	9	Wing 1-Tungsawang	100 250	10 10	1,000 2,500
	-Regular	10	Army camp -Bus term. 2	120	4	480
	-Regular -Hirpick up -Air Bus	11	Friendship-ground water Proj.	72 80 20	17 17 9	1,224 1,360 180
	-Regular	12	Ban Palai-Watliab	50	14	700
	-Regular -Hirpickup	13	Nongpilom -Suanpak	100 100	7 7	700 700
	-Regular -Air Bus	14	Ratchamong kol-SUT.	55 55	22 22	1,210 1,210
	-Air Bus	15	Public Market 1-2	56	6	336
	-Air Bus	16	Market 2-Rat chamonkol	60	17	1,020
	-Air Bus	17	SUT.-Bantalay	56	21	1,176
	-Air Bus	18	Train stat.-Air base	28	10	280
	-Hire pick ups	19	Market 1-Ban Tangtar	37	8	296
Total	-Regular -Hirepickup -Air Bus			1,501 1,823 455		20,086 17,244 6,362

Source: Nakhon Ratchasima Provincial Transport Office (1998).

Table C-8. Number of train passing through Nakhon Ratchasima municipality.

Item	Track No.	Time rate inside NKRM min.	Distance inside NKRM km/unit	Engine type	Fuel consumption rate (km/L)
1	231	10	3	Commin N855R2	4.5
2	232	10	3		4.5
3	233	17	8		4.5
4	234	17	8		4.5
5	415	12	5		4.5

Table C-8 (cont'd). Number of train passing through Nakhon Ratchasima municipality.

Item	Track No.	Time rate inside NKRM min.	Distance inside NKRM km/unit	Engine type	Fuel consumption rate (km/L)
6	416	12	5	Commin N855R2	4.5
7	417	12	5		4.5
8	418	12	5		4.5
9	419	12	5		4.5
10	421	12	5		4.5
11	424	12	5		4.5
12	426	12	5		4.5
13	427	12	5		4.5
14	428	12	5		4.5
15	429	12	5		4.5
16	431	17	8		4.5
17	432	17	8		4.5
18	21	12	8	Commin N855R2 With Perkins 112 HP (20 l/hr)	1.60
19	22	12	8		1.60
20	71	12	8		1.60
21	72	12	8		1.60
22	73	12	8		1.60
23	74	12	8		1.60
24	77	12	8		1.60
25	78	12	8		1.60
26	67	12	8	Alsthom, or (GE)	0.2
27	68	12	8		0.2
28	135	12	8		0.2
29	136	12	8		0.2
30	141	12	8		0.2
31	142	12	8		0.2
32	227	12	8		0.2
33	228	12	8		0.2
34	229	12	8		0.2
35	230	12	8		0.2
36	483	10	5		0.2
37	484	10	5		0.2
38	501	20	8		0.2
39	502	20	8		0.2
40	527	20	8		0.2
41	528	20	8		0.2
42	543	20	8		0.2
43	544	20	8		0.2
44	591	20	8		0.2

Table C-8 (cont'd). Number of train passing through Nakhon Ratchasima municipality.

Item	Track No.	Time rate inside NKRM min.	Distance inside NKRM km/unit	Engine type	Fuel consumption rate (km/L)
45	592	20	8	Alsthom, or (GE)	0.2
46	595	20	8		0.2
47	595	20	8		0.2

APPENDIX D

Data Information for Sampling Stations

Table D-1. Comparison of each stations of air pollutants in Nakhon Ratchasima Municipality (preliminary test).

Dura- tion	Gases & STD.	Station						Mean
		A1 Mon. 8 Nov.	A2 Thu. 11 Nov.	A3 Fri. 12 Nov.	A4 Sat. 13 Nov.	A5 Mon. 15 Nov.	A6 Tue. 16 Nov.	
6:30 - 7:30	Carbon monoxide (CO) ppm 30 (1 h)	-	-	a) 1.630 b) 3.400 c) 6.780	a) 0.340 b) 1.890 c)2.890	a) 0.000 b) 4.460 c)11.22	a) 1.000 b) 4.330 c)27.88	a) 0.74 b) 3.52 c) 12.19
8:00 – 9:00		a)0.00 b) 0.050 c) 0.700	a) 0.00 b) 0.060 c)1.760	a) 0.00 b) 0.310 c) 5.750	a) 0.00 b) 1.120 c)7.330	a) 0.000 b) 5.149 c)7.957	a) 0.00 b) 1.810 c)14.26	a) 0.00 b) 1.42 c) 6.29
12:00 – 13:00		a)0.000 b) 0.120 c) 5.490	a) 0.000 b) 0.260 c)6.810	a) 0.240 b) 5.580 c)17.83	a) 0.00 b) 0.350 c)5.480	Error	a) 0.00 b) 0.310 c)2.910	a) 0.05 b) 1.32 c) 7.70
14:30 – 15:30		a)0.000 b) 0.120 c) 1.190	a) 0.010 b) 2.560 c)8.240	a) 0.00 b) 1.180 c) 2.930	a) 0.00 b) 1.090 c)5.550	a) 8.850 b) 12.32 c)17.29	a) 0.00 b) 0.790 c)6.190	a) 1.48 b) 3.01 c) 6.90
16:00 – 17:00		a)0.000 b) 0.120 c) 6.220	a) 0.210 b) 0.240 c)2.620	a) 0.00 b) 0.920 c) 8.110	a) 0.000 b) 0.000 c)0.240	a) 0.00 b) 0.200 c)3.230	a) 0.00 b) 1.230 c)37.45	a) 0.04 b) 0.45 c) 9.65
18:00 – 19:00		a)0.210 b) 1.650 c) 9.970	Cancel (Rain)	a)0.00 b) 0.830 c) 4.940	a) 0.000 b) 1.299 c)2.830	a)0.00 b) 1.050 c)4.600	a)0.00 b) 0.020 c)1.060	a) 0.04 b) 0.97 c) 4.68
Mean		a)0.04 b) 0.41 c) 4.71	a)0.06 b) 0.78 c) 4.86	a)0.31 b) 2.04 c) 7.72	a) 0.06 b) 0.96 c) 4.05	a) 1.77 b) 4.64 c) 8.86	a) 0.17 b) 1.42 c) 14.96	a) 0.39 b) 1.74 c) 7.53

Note: a) = Minimum value, b) = Average value, and c) = Maximum value

Table D-1 (cont'd). Comparison of each stations of air pollutants in Nakhon Ratchasima municipality (preliminary test).

Dura-tion	Gases & STD.	Station						Mean
		A1 Mon. 8 Nov.	A2 Thu. 11 Nov.	A3 Fri. 12 Nov.	A4 Sat. 13 Nov.	A5 Mon. 15 Nov.	A6 Tue. 16 Nov.	
6:30 - 7:30	Benzene (C_6H_6) ppm	-	-	a) 0.730 b) 1.975 c) 12.67	a) 0.924 b) 2.180 c)2.967	a) 0.000 b) 0.305 c)0.664	a) 0.680 b) 1.566 c)2.511	a) 0.58 b) 1.51 c) 4.70
8:00 – 9:00	10 (1-h)	a) 0.00 b) 0.000 c) 0.000	a) 0.000 b) 0.004 c)0.010	a) 0.00 b) 0.149 c) 1.460	a) 0.00 b) 0.010 c)0.504	a) 0.000 b) 1.650 c)9.970	a) 0.00 b) 0.010 c)0.605	a) 0.00 b) 0.30 c) 2.09
12:00 – 13:00		a)0.000 b) 0.502 c) 2.514	a) 0.325 b) 5.775 c)10.05	a) 0.00 b) 0.771 c)1.764	a) 0.00 b) 3.745 c)7.435	Error	a) 0.00 b) 6.225 c)49.16	a) 0.07 b) 3.40 c) 14.18
14:30 – 15:30		a)0.000 b) 0.000 c) 0.019	a) 0.000 b) 2.217 c)4.095	a) 0.00 b) 0.120 c) 1.100	a) 0.000 b) 0.000 c)0.170	a) 0.00 b) 3.435 c)7.025	a) 0.00 b) 3.916 c)8.415	a) 0.00 b) 1.61 c) 3.47
16:00 – 17:00		a)2.184 b) 5.149 c) 7.957	Error rain	a) 0.00 b) 0.019 c) 0.904	a) 0.000 b) 1.502 c)3.514	a) 0.00 b) 0.004 c)0.300	a) 0.00 b) 0.004 c)0.410	a) 0.44 b) 1.34 c) 2.62
18:00 – 19:00		a)2.540 b) 6.921 c) 10.10	Cancel (Rain)	a) 0.00 b) 0.315 c) 1.129	a) 0.000 b) 2.111 c)4.185	a) 0.00 b) 0.000 c)0.331	a) 0.00 b) 0.000 c)0.325	a) 0.51 b) 1.87 c) 3.21
Mean		a) 0.94 b) 2.51 c) 4.12	a) 0.11 b) 2.67 c) 4.72	a) 0.12 b) 0.56 c) 3.17	a) 0.15 b) 1.76 c) 3.13	a) 0.00 b) 1.08 c) 3.66	a) 0.11 b) 1.95 c) 10.24	a) 0.27 b) 1.73 c) 4.84

Note: a) = Minimum value, b) = Average value, and c) = Maximum value

Table D-1 (cont'd). Comparison of each stations of air pollutants in Nakhon Ratchasima municipality (preliminary test).

Dura-tion	Gases & STD.	Station						Mean
		A1 Wed. 8 Dec.	A2 Thu. 11 Nov.	A3 Fri. 12 Nov.	A4 Sat. 13 Nov.	A5 Mon. 15 Nov.	A6 Tue. 16 Nov.	
6:30 am to 6:30 pm (12-h)	Sulfur dioxide (SO_2) ppm 0.12 (24 h)	9.96×10^{-5}	706×10^{-5}	0.10	511×10^{-5}	37.6×10^{-5}	327×10^{-5}	0.05
6:30 am to 6:30 pm (12-h)	Nitro gen dioxide (NO_2) ppm 0.04 (24 h)	9.93×10^{-5}	0.39×10^{-5}	4.85×10^{-5}	4.05×10^{-5}	3.83×10^{-5}	3.32×10^{-5}	4.40×10^{-5}
6:30 am to 6:30 pm (12-h)	PM_{10} $\mu g/m^3$ 120 (24 h)	57.94	368.34	173.39	211.87	342.16	186.77	223.41

Note: a) = Minimum value, b) = Average value, and c) = Maximum value

Table D-2. Mass concentration of suspended particulate (PM_{10}).

Date	Sta-tions	Temperature (start) ^{0}C	Flow Rate (Y) ft^3 /min	Time h	Pressure (start) mbar	Initial weight of filter g	Final weight of filter g	Weight of particular g	PM_{10} $\mu g/m^3$
	Preliminary test								
8 Nov.	A1	25	52.66	12	990	3.6849	4.5459	0.8605	672.36
11 Nov.	A2	25	48.44	9	990	4.5878	4.9334	0.3456	368.34
12 Nov.	A3	25	45.75	12	991	4.5982	4.8087	0.2267	173.39
13 Nov.	A4	26	41.08	12	991	4.5688	4.8007	0.2319	211.87
15 Nov.	A5	25	46.00	12	991	4.5832	5.0051	0.4219	342.16
16 Nov.	A6	24	50.92	12	996	4.6311	4.8850	0.2539	186.77
	Re – preliminary test								
8 Dec.	A1	20	39.50	8	1002	4.3597	4.3977	0.0380	57.94
	In-depth investigation I (location A5)								
25 Nov.	A5-1	34	42.00	12	991	4.3430	4.6572	0.3142	89.44
26 Nov.	A5-2	23	36.83	12	992	4.6338	4.8259	0.1921	195.59
27 Nov.	A5-3	24	46.50	12	992	4.6527	4.9326	0.2799	239.94
28 Nov.	A5-4	22	46.92	12	994	4.6567	4.8650	0.2083	198.58
29 Nov.	A5-5	24	46.58	12	995	4.3833	4.8215	0.4382	359.30
30 Nov.	A5-6	19	44.88	24	998	4.6435	5.1338	0.4903	209.43
	In-depth investigation II (location A6)								
2 Dec.	A6-1	19	51.33	12	998	4.6684	4.8025	0.1341	109.80
3 Dec.	A6-2	21	46.08	12	997	4.3994	4.5635	0.1641	150.22
4 Dec.	A6-3	21	40.25	12	998	4.3817	4.4842	0.1025	100.47
5 Dec.	A6-4	20	54.83	12	998	4.3688	4.4795	0.1107	86.65
6 Dec.	A6-5	20	56.08	12	999	4.3378	4.4194	0.0816	63.07
7 Dec.	A6-6	19	54.79	24	1000	4.3764	4.5982	0.2218	83.59

Table D-3. Comparison of CO in Nakhon Ratchasima municipality (25 Nov. to 1 Dec.1999) (in-depth investigation).

Duration	Gases & STD.	Station : A5							Mean
		Thu. 25 Nov.	Fri. 26 Nov.	Sat. 27 Nov.	Sun. 28 Nov.	Mon. 29 Nov.	Tue. 30 Nov.	Wed. 1 Dec.	
6:30 - 7:30	Carbon monoxide	a)4.87 b) 8.59 c) 12.09	a) 0.00 b) 4.08 c)10.06	a) 0.00 b) 14.29 c)22.07	a) 0.08 b) 4.03 c)7.56	a) 1.70 b) 7.85 c)20.00	a) 0.00 b) 16.37 c)32.93	a) 0.00 b) 1.22 c)6.41	a) 0.95 b) 8.06 c)15.87
8:00 – 9:00	(CO) ppm	a) 0.00 b) 0.01 c)0.87	a) 0.00 b) 0.34 c)7.88	a) 0.00 b) 0.14 c)5.36	a) 0.00 b) 0.04 c)1.24	a) 0.00 b) 0.00 c)0.62	a) 0.00 b) 0.05 c)1.22	a) 0.00 b) 0.11 c)4.21	a) 0.00 b) 0.10 c) 3.06
12:00 – 13:00	30 (1 h)	a) 0.00 b) 0.71 c)0.92	a) 0.00 b) 0.00 c)0.36	a) 0.00 b) 0.03 c)1.88	a) 0.00 b) 0.16 c)2.33	a) 0.00 b) 0.07 c)1.46	a) 0.00 b) 0.06 c)2.60	a) 0.00 b) 0.06 c)2.90	a) 0.00 b) 0.16 c) 1.78
14:30 – 15:30		a) 0.00 b) 1.38 c)7.27	a) 0.00 b) 0.75 c)3.92	a) 0.00 b) 0.06 c)2.00	a) 0.00 b) 0.37 c)2.92	a) 0.41 b) 1.52 c)4.87	a) 0.00 b) 0.16 c)4.19	a) 0.00 b) 0.41 c)3.90	a) 0.06 b) 0.66 c) 4.15
16:00 – 17:00		a) 0.00 b) 0.08 c)1.89	a) 0.00 b) 1.97 c)6.79	a) 0.00 b) 0.03 c)0.76	a) 0.00 b) 0.34 c)7.24	a) 0.00 b) 0.45 c)3.86	a) 0.00 b) 0.28 c)14.55	a) 0.00 b) 0.16 c)4.03	a) 0.00 b) 0.47 c) 5.59
18:00 – 19:00		a) 0.00 b) 0.055 c)5.05	a) 0.00 b) 0.00 c)0.18	a) 0.00 b) 0.08 c)3.66	a) 0.00 b) 0.44 c)2.81	a) 0.00 b) 0.95 c)5.78	a) 0.31 b) 4.30 c)10.67	a) 0.00 b) 4.17 c)32.00	a) 0.04 b) 1.43 c) 8.59
Mean		a) 0.81 b) 1.80 c)4.68	a) 0.00 b) 1.19 c) 4.87	a) 0.00 b) 2.44 c) 5.96	a) 0.01 b) 0.90 c) 4.02	a) 0.28 b) 1.81 c) 6.10	a) 0.05 b) 3.54 c) 11.03	a) 0.00 b) 1.02 c) 8.91	a) 0.18 b) 1.81 c) 6.51

Note: a) = Minimum value, b) = Average value, and c) = Maximum value

Table D-4. Comparison of benzene in Nakhon Ratchasima municipality (25 Nov. to 1 Dec.1999) (in-depth investigation).

Dura-tion	Gases & STD.	Station : A5							Mean
		Thu. 25 Nov.	Fri. 26 Nov.	Sat. 27 Nov.	Sun. 28 Nov.	Mon. 29 Nov.	Tue. 30 Nov.	Wed. 1 Dec.	
6:30 - 7:30	Benzene (C_6H_6) ppm	a)0.54 b)1.62 c) 2.24	a)0.00 b) 0.11 c) 1.49	a) 0.00 b) 0.18 c) 1.31	a)0.33 b) 1.46 c) 2.75	a) 0.40 b) 0.72 c) 3.90	a) 0.00 b) 0.74 c) 3.17	a) 0.00 b) 0.27 c) 1.17	a) 0.18 b) 0.73 c) 2.29
8:00 – 9:00	10	a) 0.00 b) 0.00 c) 0.50	a) 0.00 b) 0.00 c)0.06	a) 0.00 b) 0.01 c) 0.74	a) 4.87 b) 8.59 c) 12.09	a) 0.00 b) 0.00 c) 0.30	a) 0.00 b) 0.00 c) 0.09	a) 0.00 b) 0.00 c) 0.16	a) 0.70 b) 1.23 c) 1.99
12:00 – 13:00		a)0.00 b) 0.00 c) 0.34	a) 0.00 b) 0.00 c) 0.06	a) 0.00 b) 0.01 c)0.75	a) 0.00 b) 0.00 c) 0.06	a) 0.00 b) 0.00 c) 0.23	a) 0.00 b) 0.00 c) 0.08	a) 0.00 b) 0.00 c) 0.18	a) 0.00 b) 0.00 c) 0.24
14:30 – 15:30		a) 0.00 b) 2.90 c) 6.35	a) 0.00 b) 5.04 c) 13.06	a) 0.00 b) 0.04 c) 0.98	a) 0.00 b) 0.43 c)1.66	a) 0.00 b) 0.00 c) 0.30	a) 0.00 b) 0.00 c) 0.00	a) 0.00 b) 0.00 c) 0.51	a) 0.00 b) 1.20 c) 3.27
16:00 – 17:00		a) 0.00 b) 0.00 c) 0.40	a) 0.00 b) 0.44 c) 1.71	a) 0.00 b) 0.02 c) 0.82	a) 0.00 b) 0.41 c) 1.66	a) 0.00 b) 0.00 c)0.29	a) 0.00 b) 0.01 c) 3.34	a) 0.00 b) 0.00 c) 0.77	a) 0.00 b) 0.13 c)1.28
18:00 – 19:00		a)0.63 b) 6.24 c) 10.66	a) 0.00 b) 2.68 c) 5.82	a) 0.00 b) 0.01 c) 1.82	a) 0.44 b) 1.98 c) 3.62	a) 5.83 b) 11.32 c) 16.52	a) 1.31 b) 10.50 c)18.25	a) 0.00 b) 7.67 c) 13.85	a) 1.17 b) 5.77 c) 10.08
Mean		a) 0.20 b) 1.79 c) 3.42	a) 0.00 b) 1.38 c) 3.70	a) 0.00 b) 0.05 c) 1.07	a) 0.94 b) 2.15 c) 3.64	a) 1.04 b) 2.01 c) 3.59	a) 0.22 b) 1.88 c) 4.16	a) 0.00 b) 1.32 c) 2.77	a) 0.34 b) 1.51 c) 3.19

Note: a) = Minimum value, b) = Average value, and c) = Maximum value

Table D-5. Comparison of SO_2, NO_2, and PM_{10} in Nakhon Ratchasima municipality (25 Nov. to 1 Dec.1999) (in-depth investigation).

Dura-tion	Gases & STD.	Station : A5							Mean
		Thu. 25 Nov.	Fri. 26 Nov.	Sat. 27 Nov.	Sun. 28 Nov.	Mon. 29 Nov.	Tue. 30 Nov.	Wed. 1 Dec.	
6:30 am to 6:30 pm (12-h)	Sulfur dioxide (SO_2) ppm 0.12 (24 h)	137×10^{-5}	86.9×10^{-5}	199×10^{-5}	123×10^{-5}	49.3×10^{-5}	110×10^{-5} 6:30 am–6:30 am (24 h)		118×10^{-5}
6:30 am to 6:30 pm (12-h)	Nitro gen dioxide (NO_2) ppm 0.04 (24 h)	3.66×10^{-5}	4.02×10^{-5}	3.77×10^{-5}	0.3×10^{-5}	4.77×10^{-5}	2.98×10^{-5} 6:30 am–6:30 am (24 h)		3.25×10^{-5}
6:30 am to 6:30 pm (12-h)	PM_{10} $\mu g/m^3$ 120 (24 h)	89.44	195.59	239.94	198.58	359.30	209.43 6:30 am–6:30 am (24 h)		215.38

Table D-6. Comparison of CO in Nakhon Ratchasima municipality (2 to 8 Dec.1999) (in-depth investigation).

Dura-tion	Gases & STD.	Station : A6							Mean
		Thu. 2 Dec.	Fri. 3 Dec.	Sat. 4 Dec.	Sun. 5 Dec.	Mon. 6 Dec.	Tue. 7 Dec.	Wed. 8 Dec.	
6:30 - 7:30	Carbon mon oxide (CO) ppm 30 (1 h.)	a) 0.00 b) 2.38 c) 13.82	a) 0.00 b) 0.05 c) 0.91	a) 0.00 b) 0.67 c) 3.68	a) 0.00 b) 2.81 c) 6.24	a) 0.00 b) 1.49 c) 3.98	a) 0.00 b) 1.32 c) 3.62	a) 0.98 b) 2.66 c) 6.84	a) 0.14 b) 1.63 c) 5.58
8:00 – 9:00		a) 0.00 b) 4.10 c)27.10	a) 0.00 b) 0.60 c) 11.20	a) 0.00 b) 0.29 c) 4.57	a) 0.00 b) 0.03 c) 0.96	a) 0.00 b) 0.06 c) 2.11	a) 0.00 b) 0.57 c) 22.16	a) 0.00 b) 0.00 c) 0.65	a) 0.00 b) 0.81 c) 9.82
12:00 – 13:00		a) 0.00 b) 0.01 c) 0.79	a) 0.00 b) 2.56 c)17.59	a) 0.00 b) 0.00 c) 0.46	a) 0.00 b) 0.03 c) 2.46	a) 0.00 b) 0.00 c) 0.57	a) 0.00 b) 0.03 c) 1.59	a) 0.00 b) 0.16 c) 3.69	a) 0.00 b) 0.40 c) 3.88
14:30 – 15:30		a) 0.00 b) 0.77 c)5.64	a) 0.00 b) 2.26 c) 19.36	a) 0.00 b) 0.02 c) 2.31	a) 0.00 b) 1.91 c) 5.40	a) 0.00 b) 0.20 c) 2.61	a) 0.00 b) 0.30 c) 5.88	a) 0.00 b) 0.00 c) 0.07	a) 0.00 b) 0.78 c) 5.90
16:00 – 17:00		a) 0.00 b) 0.08 c)6.13	a) 0.00 b) 0.08 c) 2.65	a) 0.00 b) 0.05 c) 4.48	a) 0.00 b) 1.92 c) 14.94	a) 0.00 b) 0.42 c) 1.88	a) 0.00 b) 0.11 c) 4.21	a) 0.00 b) 0.35 c) 1.73	a) 0.00 b) 0.43 c) 5.15
18:00 – 19:00		a) 1.90 b) 5.89 c)8.41	a) 0.00 b) 3.11 c) 26.15	a) 0.65 b) 2.84 c) 22.24	a) 0.00 b) 1.92 c) 14.97	a) 0.00 b) 0.59 c) 6.31	a) 0.44 b) 3.81 c) 10.12	a) 0.00 b) 1.97 c) 10.62	a) 0.50 b) 2.88 c) 14.12
Mean		a) 0.32 b) 2.21 c) 10.32	a) 0.00 b) 1.44 c) 12.98	a) 0.11 b) 0.65 c) 6.29	a) 0.00 b) 1.44 c) 7.50	a) 0.00 b) 0.46 c) 2.91	a) 0.07 b) 1.02 c) 7.93	a) 0.16 b) 0.86 c) 3.93	a) 0.11 b) 1.16 c) 7.41

Note: a) = Minimum value, b) = Average value, and c) = Maximum value

Table D-7. Comparison of benzene in Nakhon Ratchasima municipality (2 to 8 Dec.1999) (in-depth investigation).

Dura-tion	Gases & STD.	Station : A6							Mean
		Thu. 2 Dec.	Fri. 3 Dec.	Sat. 4 Dec.	Sun. 5 Dec.	Mon. 6 Dec.	Tue. 7 Dec.	Wed. 8 Dec.	
6:30 - 7:30	Benzene (C_6H_6) ppm	a) 0.00 b) 0.07 c) 0.83	a) 0.00 b) 0.01 c) 0.13	a) 0.00 b) 0.00 c) 0.20	a) 0.00 b) 0.01 c) 0.58	a) 0.00 b) 0.00 c) 0.19	a) 0.00 b) 0.00 c) 0.08	a) 0.00 b) 0.27 c) 0.73	a) 0.00 b) 0.05 c) 0.39
8:00 – 9:00	10	a) 0.00 b) 0.00 c) 0.19	a) 0.00 b) 0.00 c) 0.30	a) 0.00 b) 0.00 c) 0.25	a) 0.00 b) 0.00 c) 0.30	a) 0.00 b) 0.00 c) 0.30	a) 0.00 b) 0.00 c) 0.07	a) 0.00 b) 0.00 c) 0.00	a) 0.00 b) 0.00 c) 0.20
12:00 – 13:00		a) 0.00 b) 0.00 c) 0.28	a) 0.00 b) 0.00 c) 0.09	a) 0.00 b) 0.00 c) 0.26	a) 0.00 b) 0.00 c) 0.06	a) 0.00 b) 0.00 c) 0.46	a) 0.00 b) 0.00 c) 0.00	a) 0.00 b) 0.00 c) 0.00	a) 0.00 b) 0.00 c) 0.16
14:30 – 15:30		a) 0.00 b) 6.27 c) 12.47	a) 0.00 b) 0.07 c) 0.80	a) 0.00 b) 0.00 c) 0.00	a) 0.00 b) 0.00 c) 0.09	a) 0.00 b) 0.24 c) 1.17	a) 0.00 b) 0.17 c) 3.52	a) 0.00 b) 0.00 c) 0.00	a) 0.00 b) 0.96 c) 2.58
16:00 – 17:00		a) 0.00 b) 0.00 c) 0.28	a) 0.00 b) 0.56 c) 2.03	a) 0.00 b) 0.00 c) 0.19	a) 0.00 b) 0.60 c) 2.23	a) 0.00 b) 0.41 c) 1.99	a) 0.00 b) 1.68 c) 4.97	a) 0.00 b) 0.18 c) 1.43	a) 0.00 b) 0.49 c) 1.87
18:00 – 19:00		a) 1.91 b) 5.51 c) 9.03	a) 0.00 b) 1.01 c) 5.27	a) 0.00 b) 0.24 c) 1.83	a) 0.00 b) 1.97 c) 9.27	a) 0.00 b) 0.46 c)3.12	a) 0.00 b) 2.63 c) 5.83	a) 0.00 b) 4.69 c) 14.42	a) 0.27 b) 2.36 c) 6.97
Mean		a) 0.32 b) 1.98 c) 3.85	a) 0.00 b) 0.28 c) 1.44	a) 0.00 b) 0.04 c) 0.46	a) 0.00 b) 0.43 c) 2.09	a) 0.00 b) 0.19 c) 1.21	a) 0.00 b) 0.75 c) 2.41	a) 0.00 b) 0.86 c) 2.76	a) 0.05 b) 0.64 c) 2.03

Note: a) = Minimum value, b) = Average value, and c) = Maximum value

Table D-8. Comparison of SO_2, NO_2, and PM_{10} in Nakhon Ratchasima municipality (2 to 8 Dec.1999) (in-depth investigation).

Duration	Gases & STD.	Station : A 6							Mean
		Thu. 2 Dec.	Fri. 3 Dec.	Sat. 4 Dec.	Sun. 5 Dec.	Mon. 6 Dec.	Tue. 7 Dec.	Wed. 8 Dec.	
6:30 am to 6:30 pm (12-h)	Sulfur dioxide (SO_2) ppm 0.12 (24 h)	256×10^{-5}	197×10^{-5}	86×10^{-5}	48.7×10^{-5}	159×10^{-5}	97.4×10^{-5} 6:30 am-6:30 am (24 h)		141×10^{-5}
6:30 am to 6:30 pm (12-h)	Nitrogen dioxide (NO_2) ppm 0.04 (24 h)	4.51×10^{-5}	2.65×10^{-5}	4.19×10^{-5}	3.50×10^{-5}	2.97×10^{-5}	3.51×10^{-5} 6:30 am-6:30 am (24 h)		3.56×10^{-5}
6:30 am to 6:30 pm (12-h)	PM_{10} $\mu g/m^3$ 120 (24 h)	109.80	150.22	100.47	86.65	63.07	83.59 6:30 am-6:30 am (24 h)		98.97

Table D-9. Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Thursday 25 November 1999
Location: Intersection to Chakarat district
Road: Ratchasima-Chockchai

Duration	Motor-cycle	3 -wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	1,267	41	359	953	212	2,832
08:00-09:00	775	38	508	1,411	271	3,003
12:00-13:00	552	38	296	1,118	224	2,228
14:30-15:30	462	52	357	1,315	240	2,426
16:00-17:00	487	47	492	1,301	248	2,575
18:00-19:00	703	48	405	1,174	154	2,484
Mean	708	44	403	1,212	225	

Table D-9 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Friday 26 November 1999
Location: Intersection to Chakarat district
Road: Ratchasima-Chockchai

Duration	Motor-cycle	3 -wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	873	45	442	897	210	2,467
08:00-09:00	887	47	549	510	279	2,272
12:00-13:00	558	43	343	1,279	235	2,458
14:30-15:30	596	64	409	1,320	260	2,649
16:00-17:00	781	45	570	1,631	247	3,274
18:00-19:0	827	65	492	1,265	186	2,835
Mean	754	52	468	1,150	236	

Table D-9 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Saturday 27 November 1999
Location: Intersection to Chakarat district
Road: Ratchasima-Chockchai

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	784	41	234	677	170	1,906
08:00-09:00	719	40	371	1,170	226	2,526
12:00-13:00	520	49	458	1,215	214	2,456
14:30-15:30	486	47	339	1,136	225	2,233
16:00-17:00	533	37	374	1,221	204	2,369
18:00-19:00	753	46	421	1,112	142	2,474
Mean	633	43	366	1,089	197	

Table D-9 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Sunday 28 November 1999
Location: Intersection to Chakarat district
Road: Ratchasima-Chockchai

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	706	46	169	586	136	1,643
08:00-09:00	672	26	332	927	168	2,125
12:00-13:00	614	49	393	1,060	206	2,322
14:30-15:30	407	30	283	1,029	161	1,910
16:00-17:00	662	62	410	1,248	173	2,555
18:00-19:00	294	57	509	1,015	130	2,005
Mean	559	45	349	978	162	

Table D-9 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Monday 29 November 1999
Location: Intersection to Chakarat district
Road: Ratchasima-Chockchai

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	764	44	337	1,785	107	3,037
08:00-09:00	473	29	283	1,705	279	2,769
12:00-13:00	468	34	347	1,575	248	2,672
14:30-15:30	418	36	269	1,531	277	2,531
16:00-17:00	304	25	210	2,055	328	2,922
18:00-19:00	486	41	232	1,326	180	2,265
Mean	486	35	280	1,663	237	

Table D-9 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Tuesday 30 November 1999
Location: Intersection to Chakarat district
Road: Ratchasima-Chockchai

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	817	78	417	949	193	2,454
08:00-09:00	651	47	379	1,667	274	3,018
12:00-13:00	408	33	269	1,394	231	2,335
14:30-15:30	320	24	287	1,523	328	2,482
16:00-17:00	533	36	423	1,967	345	3,304
18:00-19:00	515	37	234	1,051	198	2,035
Mean	541	43	335	1,425	262	

Table D-9 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Wednesday 1 December 1999
Location: Intersection to Chakarat district
Road: Ratchasima-Chockchai

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	1,031	43	426	968	187	2,655
08:00-09:00	954	40	495	1,721	266	3,476
12:00-13:00	526	44	366	1,218	213	2,367
14:30-15:30	664	52	404	1,377	255	2,752
16:00-17:00	491	37	405	1,826	285	3,044
18:00-19:00	581	60	398	1,392	192	2,623
Mean	708	46	416	1,417	233	

Table D-10. Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Thursday 2 December 1999
Location: The night bazaar commercial market
Road: Chomphol

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	324	33	241	300	22	920
08:00-09:00	539	65	297	676	19	1,596
12:00-13:00	479	51	350	889	37	1,806
14:30-15:30	652	46	382	857	34	1,971
16:00-17:00	535	81	326	694	33	1,669
18:00-19:00	523	93	326	474	19	1,435
Mean	509	62	320	648	27	

Table D-10 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Friday 3 December 1999
Location: The night bazaar commercial market
Road: Chomphol

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	294	24	168	292	24	802
08:00-09:00	472	48	309	729	15	1,573
12:00-13:00	372	59	295	882	32	1,640
14:30-15:30	566	62	369	888	22	1,907
16:00-17:00	649	56	449	825	24	2,003
18:00-19:00	538	89	395	606	25	1,653
Mean	482	56	331	704	24	

Table D-10 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Saturday 4 December 1999
Location: The night bazaar commercial market
Road: Chomphol

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	206	30	74	145	18	473
08:00-09:00	381	48	296	448	19	1,192
12:00-13:00	467	52	360	674	29	1,582
14:30-15:30	343	59	270	738	25	1,435
16:00-17:00	474	61	292	638	24	1,489
18:00-19:00	402	40	293	608	27	1,370
Mean	379	48	264	542	24	

Table D-10 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Sunday 5 December 1999
Location: The night bazaar commercial market
Road: Chomphol

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	236	26	102	187	19	570
08:00-09:00	330	57	144	355	14	900
12:00-13:00	275	66	330	476	20	1,167
14:30-15:30	187	52	271	280	11	801
16:00-17:00	292	79	275	389	20	1,055
18:00-19:00	340	65	280	614	21	1,320
Mean	277	58	234	384	18	

Table D-10 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Monday 6 December 1999
Location: The night bazaar commercial market
Road: Chomphol

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	136	26	61	124	14	361
08:00-09:00	284	12	50	295	15	656
12:00-13:00	379	66	154	675	29	1,303
14:30-15:30	261	81	224	632	23	1,221
16:00-17:00	316	65	265	655	21	1,322
18:00-19:00	425	54	274	615	21	1,389
Mean	300	51	171	499	21	

Table D-10 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Tuesday 7 December 1999
Location: The night bazaar commercial market
Road: Chomphol

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	252	38	133	251	23	697
08:00-09:00	498	49	366	762	19	1,694
12:00-13:00	384	63	337	988	30	1,802
14:30-15:30	312	64	264	949	27	1,616
16:00-17:00	434	82	396	836	24	1,772
18:00-19:00	344	63	243	731	27	1,408
Mean	371	60	290	753	25	

Table D-10 (cont'd). Number of vehicles during air quality monitoring in Nakhon Ratchasima municipality area.
Date: Wednesday 8 December 1999
Location: The night bazaar commercial market
Road: Chomphol

Duration	Motor-cycle	3 - wheeler	Car	Pick up	Bus, and truck	Total
06:30-07:30	281	43	173	279	35	811
08:00-09:00	437	58	348	715	23	1,581
12:00-13:00	464	49	362	765	44	1,684
14:30-15:30	498	73	312	926	36	1,845
16:00-17:00	397	55	295	733	35	1,515
18:00-19:00	503	74	288	435	26	1,326
Mean	430	59	296	642	33	

Table D-11. Classified traffic count at screen line survey in Nakhon Ratchasima Municipality.

Location (24 hour samples)	Motor-cycle	Motor tricycle	Sedan, van and pick-up	Mini-bus	Bus	Truck 4 wheel	Truck 6 to more wheel	Total
Mitraphap road direction to Bangkok	10,513	925	20,539	295	1,260	404	4,536	38,472
Mitraphap road direction to Khonkaen	7,772	1,053	19,374	550	1,117	248	4,520	34,634
Soi Kingsawairieng to Soi Samorai	1,110	79	365	16	5	15	21	1,611
Soi Kingsawairieng to Soi Sawairieng	1,072	76	339	21	7	15	24	1,554
Mukamontri road to Hue Rod Fire	12,292	1,572	9,299	255	192	64	361	24,035
Mukamontri road to Mitraphap road	12,314	1,586	9,774	313	192	77	345	24,601
In back of NKR railway station to salawan temple	1,964	86	646	1	120	9	24	2,850
In back of NKR railway station to 5 intersection	1,840	82	607	1	120	7	24	2,681
Total	48,877	5,459	60,943	1,452	3,013	843	9,861	130,438

Source: Institute of Industrial Technology (1995).

Table D-12. Mean velocity of vehicles in Nakhon Ratchasima municipality (Floating Car Techniques).

Location	Mean distance (km)	Mean time (min)	Mean velocity (km/hr)	Date record	Time record
Around city moat	18.0 17.8 17.8	40:12 41:23 46:29	27 26 23	7/3/95 " "	07:00-10:00 am 11:00-14:00 pm 16:00-19:00 pm
Inside the city West to East Rd.	21.4 20.0 21.4	55:31 53:40 64:46	23 22 20	7/3/95 " "	07:00-10:00 am 11:00-14:00 pm 16:00-19:00 pm
Inside the city North to South Rd.	10.8 10.6 10.6	30:35 20:07 30:44	21 23 21	7/3/95 " "	07:00-10:00 am 11:00-14:00 pm 16:00-19:00 pm
Mitraphap to Mukamontre Rd.	35.1 34.6 34.6	72:15 75:25 75:52	29 28 27	8/3/95 " "	07:00-10:00 am 11:00-14:00 pm 16:00-19:00 pm
Har Yak to Rat-chadamnoen Rd.	18.1 18.1 18.1	45:00 48:30 52:58	24 22 21	9/3/95 " "	07:00-10:00 am 11:00-14:00 pm 16:00-19:00 pm

Source: Institute of Industrial Technology (1995).

Table D-13. Number of vehicles at the important intersections (Intersection turning movement count). Time 07:00 am – 07:00 pm (12 hours)

Location (12 hours)	Motor cycles	Motor tricycle and all types of 4 wheel vehicles	All types of 6 or more wheel vehicles	Total	Survey date
Soi Sawairieng/ Mitraphap Rd.	13,234	33,893	7,122	54,249	8 Mar. 1995
Mitraphap/ Rat-chadamnoen/ Chumphon	25,698	42,692	4,922	73,312	8 Mar. 1995
Ratchadam-noen/Chum-phon/Assadang	27,804	30,319	2,384	60,507	9 Mar. 1995
Jomsurangyard/ Ratchadam-noen/Chum-phon/Mahatthai	33,291	36,181	1,280	70,752	14 Mar. 1995
Mitraphap/ Prajak	20,311	26,894	3,983	51,188	9 Mar. 1995
Prajak/ Assadang	14,437	13,285	1,008	28,730	14 Mar. 1995
Pratu Pee	19,412	11,946	986	32,344	7 Mar. 1995
Mahatthai/ Mitraphap	8,505	15,816	3,436	27,757	7 Mar. 1995
Total	162,692	211,030	25,127	398,839	

Source: Institute of Industrial Technology (1995).

Table D-14. Concentration of pollutants emission from 2-stroke and 4-stroke in gasoline engines.

Pollutants	2-stroke	4-stroke	Ratio of emissions from 2 to 4 stroke gasoline engines
CO (%)	3.0	3.4	1.00
HC (as hexane ppm)	5,500	850	6.50
NO_x	150	1,000	0.17

Source: Murkerjee (1988).

Table D-15. Total emission by different vehicle modes in Kathmandu valley in tonnes/year.

Vehicle type	Pollutant types					
	CO	HC	NO_x	SO_2	TSP	VOC
Truck	1,416	557	1,653	106	69	640
Bus	241	95	281	30	12	156
Minibus	85	47	45	15	17	75
Jeep	150	72	92	39	44	108
Tractor	76	42	40	13	15	67
Car	17,189	791	219	11	45	688
3 Wheeler	744	464	12	1.8	12.8	121
2 Wheeler	3,792	2,367	23	6	96	1,828
Total	23,692	4,436	2,366	223	310	3,683

Source: Malla (1993).

APPENDIX E

Vehicular Emission Control Measures

Emission Control Policy Measures

One of the important policy options for reducing emission from vehicles is to adopt vehicle emission control. This policy has been vigorously adopted in Canada, Japan, and U.S.A., and is also adopted in many of the European countries and other parts of the world at present. Some of the emission control policy measures are discussed below.

1. Change of Fuel Quality as an Option

Fuel quality is a very complex topic and quality of fuel constantly changes (within specifications) depending upon the crude oil processed and refinery configurations available. Crude oil available at different places have different properties and thus different quality. Even in the case of the same source of supply, quality of fuel changes with time. All petroleum products used in Thailand are imported from abroad. Huge investment is required to affect change in fuel quality and have to be consistent with both present and future availability of crude oil in the world market and their availability in Thailand.

2. Fuel Quality Impact on Emissions

Diesel Fuel

Under comparable conditions, CO, total HCs, and NO_x emissions from diesel engines are low in comparisons with those from gasoline engines. However, SO_2, particulate and polycyclic aromatic (expressed as soluble organic mass emissions (SOM)) are major concerns from diesel burning. Sulfur content is the most discussed property of diesel. SO_2 emitted into the atmosphere undergoes photo-chemical reactions to produce secondary particulates which are responsible for acid rain, reduction in visibility, damage to health and the environment. Another property of diesel fuel is the cetane number which is related to ignition delay in the combustion process. Cetane number has effects on fuel economy, engine noise, engine emissions, cold staring and durability of engine. The effect of cetane number on emission are summarized in Table E-1. It is observed that HC, NO_x, CO, and particulates all increase with lowering of cetane number.

Table E-1. Effect of cetane number on emission.

Parameter	% Increase by lowering cetane number from 50 to 44
NO_x	0.70
HC	0.25
CO	0.35
Particulate	0.20

Source: Mukhopadhyay and Raje (1989).

Gasoline Fuel

The question of lead in gasoline is intimately linked to the octane level of the fuel. The octane requirement of any vehicle is a function of its compression ratio and the basic engine design. If the fuel octane number is less than the design requirement of any engine then there is fuel penalty of 1.5% for each point of octane number loss. Lead is added to gasoline as a cheap mechanism to achieve a given octane number. Lead also serves to extend the valve seat life acting as a lubricant in cast iron engine blocks. However, with the advancement technology, new vehicles employ hardened material which can operate in lead free gasoline. It would be extremely hazardous to neglect the effects of lead emission on environment primarily.

Gasoline (lead free) used in Thailand is the similar level (91-95 RON) that of Europe (90-98 RON), but a little bit different from that in the North America (92-98 RON). In Thailand, gasoline used is almost lead-free.

3. Emission Control Technologies Aspects

Applying emission control technologies to reduce emissions is an effective method to achieve a desired emission reduction. Over the years, number of technologies have emerged, particularly in developed countries for application in vehicle emission reduction. Protected by cheap fuel prices, the US approach has been to achieve reductions by exhaust treatment, while the Europeans have tended to modify the engine design and combustion characteristics.

Control at source involves control of evaporative, crankcase, and exhaust emissions. For evaporative emission control, generally two basic techniques are used, namely vapor recovery system and the adsorption regeneration system. Crankcase emission control is to prevent the blowby gases from escaping into the atmosphere. However, exhaust emission control constitutes the most crucial component in the exhaust pollution control strategy and has undergone several developments commensurate with the increasingly stringent vehicular emission standards.

Carburetor adjustment, electronic fuel injection, engine reconditioning, lean-burn system, fuel modifications, turbo charging etc. are some of the control options for exhaust emission. The pollutants to be controlled from gasoline vehicles would be CO, and HC while for diesel vehicles SO_2, NO_x, and smoke have been found from this study. The following approaches have been proposed for different types of vehicles (Malla, 1993).

Diesel Vehicles

NO_x control in diesel vehicles may be achieved by Exhaust gas recirculation (EGR) or turbocharging. In this system, the air/fuel ratio is diluted by a relatively inert gas which, in turn, reduces the maximum combustion temperature, resulting in a reduction in the formation of NO_x . However, EGR affects the engine performance and it has fuel penalty of about 3-4%. In addition, acceleration and vehicle driving ability are generally poor. However, diesel price is cheap and user costs may be less. SO_2 emissions are likely to increase due to increased fuel consumption and particulate are inversely related to NO_x.

Gasoline Vehicles

Motorcycles

Some of the possible control techniques for motorcycles SI engines. There are no suitable control techniques which can effectively control HC and CO emissions. Under such circumstances, switch over from 2-stroke to 4-stroke engines is highly desirable. Table D-14 (appendix D) shows the performance of 4-stroke engine where a drastic reduction of HC emissions (one fifth of that from 2-stroke engines) can be noticed. But there is an increase in CO emissions by about 20%. NO_x emission from motorcycles are not significant due to the presence of internal EGR in 2-stroke engines.

Cars

The development of a three-way catalytic converter, has been a major achievement in terms of vehicle emission control technology, because of its ability to simultaneously control HC, CO, and NO_x. The CO and HC are oxidized over a catalyst while NO_x is reduced by a rhodium (Rh) catalyst.

Cars and motorcycles are the main targets for reducing emissions from gasoline vehicles. Although catalytic converters to cars would help to reduce both CO and HC emissions, the cost of these converters is high . Also, the fuel quality in terms of unleaded gasoline has to be ensured and complexity of repair and maintenance and its increased costs are some of the constraints with catalytic converter. However, from societal perspectives, such an option appears to be very useful in terms of reduction of emissions. Opting for 4-stroke from 2-stroke has been found beneficial on fuel efficient devices, and enforcing strict law would be necessary. Besides, 4-stroke motorcycle must be popularized for fuel saving and reduction in emissions of CO and lead.

As regards to reduction in emissions from diesel vehicles, EGR costs are significant due to fuel penalties and investment. However, applying turbocharger appears to be very attractive from both users (in terms of net benefit) and societal (in terms of reduction in emissions) perspectives.