ESTIMATION OF VEHICULAR POLUTION LOAD IN DELHI

AND IT'S CONTROL STRATEGIES

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Thermal Engineering

By

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Candidate's Declaration

I hereby declare that the work which being present in the major thesis entitled "**ESTIMATION OF VEHICLUAR POLLUTION LOAD IN DELHI AND ITS CONTROL STRATEGIES**" in the partial fulfillment for the award of the degree of **MASTER of ENGINEERING** with specialization in "**THERMAL ENGINEERING"** submitted to **Delhi College of Engineering, University of Delhi,** is an authentic record of my own work carried out under the supervisions of **Mr. Amit Pal,** Sr. Lecturer, Department of Mechanical Engineering Delhi College of Engineering, University of Delhi. I have not submitted the matter in this dissertation for the award of any other degree or diploma or any other purpose whatever.

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Certificate

This is to certify that the above statement made by Sh. RAJESH SONI is true to the best of my knowledge and belief.

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Acknowledgement

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Rajesh Soni

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ABSTRACT

Delhi is a rapidly expanding mega city. Population and vehicle use continue to expand, with vehicles being the principal source of severe air pollution. And yet, vehicle ownership is still fraction of that in industrialized countries. In this work, we attempt to untangle the complexities of Delhi's transport sector, exploring what kind of a future is likely and how it might be altered. We analyzed historical data, estimated vehicle pollution load, and examined strategies to control vehicle pollution.

One scenario representing a "business-as-usual" trajectory – is an extrapolation of present trends in Delhi, modified to reflect existing policies and commitments. This scenario results in dramatic increases in vehicle use, translating to about a fourfold increase in transport-related greenhouse gas (GHG) emissions between 2000 and 2020. The second scenario is premised on strong political and institutional leadership to enhance the economic, social, and environmental performance of Delhi's transportation system. Car use drops, and transit and bike use increase, there is major changes in the public transport system with the introduction of metro rail phase I and II. , Govt. is also planning to introduce High Capacity Buses and Mono rail. With the huge investment on road infrastructure and new technology development the pollution level is likely to come down. But even with this aggressive shift toward more environmental friendly transportation, GHG emissions may be more than double in the 20-year period. We observe that under any plausible scenario greenhouse gases will soar, but that the lower greenhouse gas path leads to far fewer emissions and much lower transport and energy costs.

INTRODUCTION

Air pollution from automobile exhaust is becoming a serious problem due to considerable increase in the number of motor vehicles in the recent years. Phenomenon of the increase of number of motor vehicles in the recent years is due to continuous expansion of transportation activities. It is envisioned that the transportation sector will show as large as about 7% global increase during this decade. The global vehicle stock is expected to be approximately double from about 400 million at present to about 1 billion vehicles by the year 2025.

The effects of automobile exhaust pollution are subtle and cumulative. Automobile emit gases as well as particulates of high molecular weight which can directly be inhaled and affect health of people. Human beings are the immediate victims from headache, dizziness, eye irritation, brain damage, respiratory problem, cancer, kidney damage and cardiovascular deaths. Many vehicle emissions have already been identified as being anything from general health hazards, and irritants, to being *carcinogenic* (able to induce cancer development), *mutagenic* (able to induce genetic mutation) and even *teratrogenic* (able to induce reproductive impairment) to humans. According to medical experts, many premature deaths are attributed to air pollution. Millions of hospital admissions and cases of minor sickness occur every year due to diseases related to air pollution.

Ambient air of urban area of high vehicular population is highly polluted with vehicular emission for example, Delhi has maximum number of vehicles in India and there are approximately three times more vehicles than Mumbai. The total vehicular pollution load in tones per day in Delhi was as high as 1046.30, compared to as low as 226.25 in Chennai and 293.71 in Kolkata in year 2001. Even Mumbai, which stands second in vehicular population, had recorded only 659.30 TPD vehicular pollution load in the same year, way below the national capital . Various agencies publish air quality data of such places. Various pollutants show alarming levels. Breathing in ambient air of urban area of high vehicular population has become difficult or unhealthy.

The environment is a major area of concern, today, and the world over. The problem has attracted in India too, as is evident from the concern voiced by the public, and the recent Supreme Court judgment of implementation of Euro norms for the case of Delhi as a pollution reduction measures.

Burning of petroleum fuel in vehicles release significant quantities of oxides of nitrogen, carbon monoxide, sulphur dioxide, lead and suspended particulate matter. Lead used in petrol to protect engines from detonation is dangerous. Diesel-powered cars produce large quantities of particulates in the form of black soot.

The various means for controlling harmful automobile exhaust emission have been developed. The purpose of such emission control system is just that; it controls the emissions and exhaust from our vehicle. Emission control systems vary between manufacturers and vehicles but they all have the same goal and use many of the same methods. The idea is to turn the harmful gases into harmless ones that don't ruin the environment. Without emission control, the carburetor and fuel tank can emit fuel vapors, the crankcase can emit blow by gases and fuel vapor, and the tail pipe can give out engine exhaust gas with pollution in it.

Good growing international concern about environmental issues in recent years had led to new proposals for strengthening exhaust emissions standards and fuel economy requirement throughout the world. To cop up these standards a reduction of major pollutants in exhaust of engines of vehicles like hydrocarbon, carbon monoxide and nitrogen oxides (known as NO_X) particulate matter like lead (Pb) etc. have been attempted.

In this report, the contribution of different types of vehicle technologies in the reduction of pollutants in the exhaust of engines has been estimated. The various means for controlling harmful automobile exhaust emission have been discussed. The benefits, which could accrue by use of the catalytic converter and other engine design improvements, including alternative technologies, are considered so that appropriate emission control technologies are adopted in the near and long term.

Catalytic converter is a device with proven technology and hence included with greater emphasis. The oxidation type catalytic converter provides atmosphere to oxidize carbon monoxide and hydrocarbons along with reducing atmosphere for the conversion of NO_x . It is to be seen that conventional oxidation catalyst and dual converter catalyst systems primarily require only a secondary air source and other advanced technology is not essential. Whereas the three-way catalyst systems require closed loop A/F control systems with associated fuel injection system, lambda sensor, air flow and temperature sensors, and electronic control unit to maintain the desired conditions in the exhaust.

Some other technologies such as exhaust gas recirculation, fuel cell, and electric /hybrid vehicular technology have also been discussed in detail. Various combinations of control technologies adopted for emission control from time to time is to be described in later section. A detailed overview of each type of emission control measures is included in subsequent sections.

1.1 Composition of an Internal Combustion Engine Exhaust

The power that propels automobiles comes from combustion chamber that is where fuel (hydrocarbons) meets air. Ideally, oxygen in the air converts all the hydrogen in the fuel into water and all the carbon into carbon dioxide. But, in reality, combustion also produces regulated pollutants like unburnt hydrocarbons, oxides of nitrogen and carbon monoxide and many other non-regulated pollutants like Aldehydes and Ketones. By weight, the presence of these non-regulated pollutants does not seem as impressive as the regulated ones, but it takes immensely less quantity for these compounds to promote the development of lung cancer.

In an engine, fuel is burnt with air. Fuel (petrol or diesel) consists of Hydrocarbons. Air mainly consists of Oxygen and Nitrogen. Air present in combustion chamber cannot burn the fuel completely. Because of such incomplete combustion, Carbon Monoxide is produced. Part of the fuel, which has not been burnt, comes out as unburnt Hydrocarbons.

The high temperature inside the engine (about 2,000 centigrade) causes the Oxygen and Nitrogen in the air to combine and form various Oxides of Nitrogen. Thus, CO, unburnt HC and NO_x come out of vehicular exhaust. All these are harmful to human beings.

The various exhaust emissions resulted due to idle combustion are as follows.

Nitrogen (N2)

It is main constituent of air; 78% part of the air is nitrogen. Most of nitrogen passes right through the engine.

Carbon dioxide (CO_2)

Carbon of fuel bonded with O_2 of air, CO_2 is formed.

Water vapor (H_2O)

Hydrogen of fuel bonded with oxygen of air and water vapors are formed.

Formation of exhaust gases depends upon the fuel used. Emissions from spark ignition and compression ignition engine differ in some respect.

1.2 Exhaust Emissions from Spark Ignition Engine

The fuel used in spark ignition engines is gasoline consisting of compounds of carbon and hydrogen called hydrocarbons (HC). The chemical composition of gasoline is 45-60% saturated hydrocarbon, 30-50% aromatic hydrocarbon and 5-10% olefin hydrocarbon. The fuel is vaporized in the carburetor or by EFI, mixed with air and combusted within the spark ignition engine. A major portion is converted to carbon dioxide (CO_2) and water (H_2O). But, in addition to oxygen, air consists of 79% of nitrogen (N_2). So, at high temperature, nitrogen oxides (NO_x such as NO, NO_2 etc) are also formed. Due to incomplete combustion regulated pollutants like unburnt hydrocarbons and carbon monoxide are produced. The carbon monoxide (CO) in the exhaust gas is due to the incomplete combustion of carbon in the fuel, which if it gets further oxidized becomes carbon dioxide (CO_2). The hydrocarbons (HC) in the exhaust gas may be due to incomplete combustion or due to fuel escape.

Engine emission from spark ignition engine depends on many factors. Large quantity of such emission is needed to be controlled. For reaching to any of pollution mitigating strategy for spark ignition engine a through and careful analysis of various factors influencing emissions is needed.

1.3 Factor influencing emissions from spark ignition engine

To reduce engine emission, the fuel which is burnt in side, must be unadulterated. There are many other factors influencing the concentration of CO, HC and NO_x in the exhaust of a spark ignition engine. The major factors and their influence are mentioned below.

Air -Fuel ratio

The air fuel ratio also plays a very important role in producing various types of emissions. The theoretical air to fuel ratio, which will allow all fuel to burn using all oxygen, is popularly known as *stoichiometric ratio*. Air for gasoline fuel or the air to fuel ratio required ideally for such combustion is 14.7: 1.This means that 14.7 kg to air will be required for perfect combustion of 1kg of gasoline. The fuel mixture actually varies from the ideal ratio quite a bit during actual driving. The mixture may lean or rich other than stoichiometric during various driving condition.

In general, the concentration of exhaust gases change according to the air-fuel ratio as the emission ratio of the different gases changes with A/F ratio. In case of CO other factors are less influencing and it could be said that it is almost singularly dependent on the air-fuel ratio.

HC and fuel consumption increase in lean vapors (high A/F ratio) because of incomplete flame propagation or because the flame is put out. With lean vapors engine output is greatly reduced and the emission ratio of the three gases increases. However, at different A/F ratio, the emission ratio of NO_x and HC move in opposite directions.

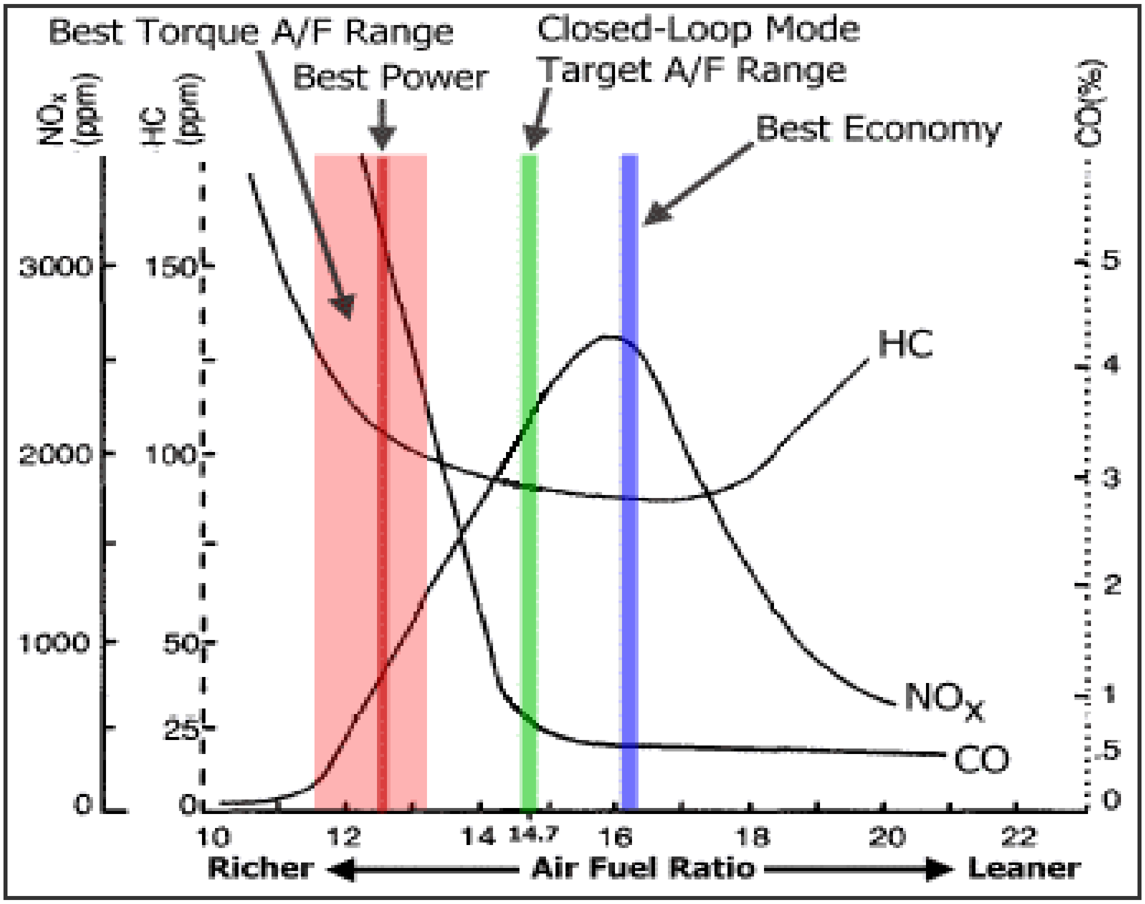

Figure1.2: The Optimal A/F Ratio

Ignition Timin

NO_x emission decrease greatly as the ignition timing is delayed; peak NOx levels are achieved at A/F ratio closer to the optimum A/F ratio. In engines without exhaust countermeasures, it can be said as a guideline that, for every delay of the ignition timing by 10° from MBT (the smallest ignition angle at which maximum torque can be achieved), a 30-40% reduction in the concentration of NO_x can be achieved. But since power output also decreases, the reduction in emission is about 20%.

Combustion gas temperature and time influence, the variation of NO_x emission ratio and the influence is greater at higher vapor concentration than at lower concentration.

Delay in ignition timing helps to reduce HC. This is because combustion is delayed and oxidation is facilitated due to the gas temperature rising in the expansion process after leaving from the exhaust valve. This influence is greater at lower vapor concentration levels.

Condition of intake vapor

Increase in the temperature of intake vapor leads to increase in concentration of NO_x. On the other hand, the intake volume also decreases resulting in reduced power and so NO_x emission ratio increases. As far as HC formation is concerned the influence is limited.

Reduction in intake pressure reduces concentration of NO_x and increases concentration of HC. Humidity reduces flame temperature resulting in considerable reduction in the concentration of NO_x. The effect is greater for the leaner vapor.

Residual gas

Increase of residual gas reduces the combusted gas temperature. So, NO_x formation is reduced but HC increases.

Circulating water temperature

Increase in circulating water temperature reduces HC slightly but increases NO_x.

Various engine characteristics

The more compact the shape of the combustion chamber i.e. the smaller the S/V ratio (ratio of surface area to volume), the lesser the output of HC and on the other hand, NOx increases. The extent is also determined by the positioning of the spark plug.

The effect of compression ratio is influenced by other factors also. However, under condition of same output and fuel efficiency, the higher the compression ratio the more the HC and NO_x decrease slightly. However, when lean vapor is used, increase in compression ratio leads to increase in NO_x emissions.

Increase in the volume of the chamber in general leads to lower concentration of HC and increased concentration of NO_x. The ratio of volume to diameter also displays a similar trend.

1.4 Exhaust Emissions from Compression Ignition Engine

Compression ignition engine produces gases like carbon dioxide (CO_2) and oxides of nitrogen (NO_x) along with particulate matter. The other exhaust emissions of diesel engine include hydrocarbons (HC), carbon monoxide and particulates. Sulphur in fuel is also emitted as SO_2 in the exhaust gases from diesel vehicles.

Hydrocarbons

Hydrocarbons are generated during starting and warming up from cold because of the volatility of diesel fuel and the short period of time available for it to evaporate before combustion begins. In these circumstances, fuel droplets, together with water vapor produced by the burning of the hydrogen content of the remainder of the fuel, issue from the cold exhaust pipe in the form of what is generally termed white smoke, but which is in fact largely a mixture of fuel and water vapors. At about 10% load and rated speed, both HC and CO output are especially sensitive to fuel quality and in particular cetane number.

During starting and warming up from cold reduces the rate of evaporation of the fuel, so that it fails to be ignited before the contents of the chamber have been cooled by expansion of the gases, to a level such that ignition can no longer occur. Similarly, the cooling effect of the expansion stroke when the engine is operating at or near full load can quench combustion in fuel-rich zones of the mixture. This is one of the potential causes of HC emissions.

Hydrocarbons in the exhaust are the principal cause of the unpleasant smell of a diesel engine. Another potential cause of hydrocarbons emission is the fuel contained in the volume between the pintle needle seat and the spray hole or holes. After the injector needle has seated and combustion has ceased, some of the trapped fuel may evaporate into the cylinder. Finally, the crevice areas, for example between the piston and cylinder walls above the top ring, also contain unburnt or quenched fractions of semi-burnt mixture. Expanding under the influence of the high temperatures due to combustion and falling pressures during the expansion stroke and forced out by the motions of the piston and rings, these vapors and gases find their way into the exhaust.

Other causes of unburnt Hydrocarbons generation are as follows.

- At low temperatures and light loads, the mixture may be too lean for efficient burning so the pre-combustion processes during the ignition delay period are partially inhibited. This is why some of the mixture subsequently fails to burn.

- The injected fuel, a higher than normal proportion of it which fails to evaporate is deposited on the combustion chamber walls. This further reduces the rate of evaporation of the fuel.

Unburnt Hydrocarbons tend to become a problem also at maximum power output, owing to the difficulty under these conditions of providing enough oxygen to burn all the fuel. As fuel delivery is increased, a critical limit is reached above which first the CO and then the HC output rise steeply. Injection systems are normally set so that fuelling does not rise up to this limit, though the CO can be removed subsequently by a catalytic converter in the exhaust system

Carbon monoxide

Even at maximum power output, there is as much as 38% of excess air in the combustion chamber. However, although carbon monoxide (CO) should not be formed, it may in fact be found in small quantities in the exhaust. The reason is partly that, in local areas of the combustion chamber, most of the oxygen has been consumed before injection ceases and therefore fuel injected into these cannot burn completely to CO2.

Particulates

Regulations define particulates as anything that is retained, at an exhaust gas temperature of 52%, by a filter having certain specified properties. They therefore include liquids as well as solids. Particle sizes from 0.01 to 10μm, the majority being well under 1.0μm. While black smoke comprises mainly carbon, the heavier particulates comprise ash and other substances, some combined with carbon. The proportions however depend on type of engine, fuel and lubricant.

POLLUTANTS FROM VEHICULAR EXHAUST AND THEIR HEALTH EFFECTS

The complete combustion of fuel composed exclusively of carbon and hydrogen, would only generate carbon dioxide and water, to the exclusion of any other harmful product. However the very short time allowed for chemical oxidation processes to take place in combustion chambers, the lack of homogeneity in the carbureted mixture, and the heterogeneity and rapid variations in temperature never allow the state of ideal thermodynamic equilibrium to be reached. This means that products of incomplete combustion are present in the exhaust, as well as sulfur compounds from sulfur bearing residues, the remaining in the fuel, where as nitrogen oxides gases are formed by high temperatures oxidation of the inert nitrogen present as a diluents in the air. The difference between emissions of gasoline and diesel fuelled engine is that the diesel engine, which operate by compression ignition, emits carbonaceous particulates that are absent in exhaust of gasoline fuelled engines. The other pollutant other than hydrocarbon, carbon monoxide and nitrogen oxides is sulfur dioxide, which varies directly with sulfur content of fuel. Pollutants like aldehydes results from combustion of alcohol fuel.

The process of formation of various products of incomplete combustion and their health effects to human health are included in this report as follows.

2.1 Carbon Monoxide (CO)

The carbon dioxide (CO_2) is final product of complete combustion of fuel composed exclusively of carbon and hydrogen. An essential step in such hydrocarbon oxidation process is CO formation.

Formation of carbon monoxide

The CO formed is then oxidized at a slower rate. The formation of CO is an essential intermediate step in the hydrocarbon oxidation process leading to the final product CO_2.

$$RH => R => RO_2 => RCHO => RCO => CO$$

(Where R represents the hydrocarbon radical)

The CO formed is then oxidized at a slower rate to CO_2 by the reaction:

$$CO + OH <=> CO_2 + H$$

The fuel oxidation rate depends on the available oxygen concentrations. The temperature of the gasses, and the time left for the reaction to take place. Time left for the reaction depends on the engine speed.

The main parameter governing CO emissions is the fuel /air ratio of the carbureted mixture. In a rich mixture, the CO concentration increases steadily with the increase in fuel/air ratio as lack of oxygen causes incomplete combustion. A first approximation of the CO concentration in the gases is given by the equilibrium of the 'water gas' reaction as follows.

$$CO + H_2O <=> H_2 + CO_2$$

(For a temperature of about 1600 to1700 K)

The freezing of the reaction at these temperatures corresponds to equilibrium constant:

$$K= [CO]\,[H_2O] / [CO_2]\,[H_2]$$

(Equilibrium constant of about 3.5 to 3.8)

In a lean mixture, the CO concentrations are low and vary only slightly with the fuel/air ratio, but they are nevertheless higher than those predictable by kinetic models. This could be due to incomplete oxidation during the expansion phase of the hydrocarbons desorbed, the oil films, or the crevices of the combustion chamber [4].

Spark ignition engines run at partial load near a fuel/air ratio of 1 and in a rich mixture at full load and when starting if the choke is used. Under these conditions, CO emissions are significant. However, the CO levels in the spark ignition engine exhaust are always lower than the maximum values present in the combustion chamber.

The means applied so far to reduce CO emissions consist in improving the uniformity of the composition of the carbureted mixture and in making the intake mixture leaner. In multi-cylinder engines in particular, the dispersion in the fuel /air ratio between cylinders is one cause of increased CO emissions. In addition, during the transient acceleration and deceleration phases, more accurate control of the quantity of fuel introduced reduces the CO emitted.

The equilibrium concentration of carbon monoxide (CO) in exhaust gas (concentration in the composition of exhaust gas kept for a sufficiently long time under constant temperature and pressure) not only decreases sharply with increase of air- fuel ratio, it also decreases considerably with a reduction in the exhaust gas temperature. If chemical equilibrium is maintained, at any exhaust temperature, the concentration of CO is extremely low when O_2 is plentiful as in lean vapor.

The concentration of CO in exhaust gas has an almost fixed relation to the air-fuel ratio. Below an A/F ratio of 16 it increases rapidly. Also, if the quality of vapor is inconsistent, extreme cases of localized deprivation of oxygen may cause flame to be put out due to cooling and the concentration of CO increases beyond the CO levels, associated with a constant air-fuel ratio.

Carbon monoxide’s effects on health

Carbon monoxide formed during the combustion of fuel in the vehicles is one of the lethal gases known. This is poisonous gas that is color less and odor less. It affects health by displacing oxygen from hemoglobin and preventing the passage of oxygen from the lungs to the bloodstream thus suffocating the blood tissues. The toxicity of CO is well known. It is mortal above one thousand ppm. It can also act in much lower concentrations, due to its affinity for blood hemoglobin that is 240 times greater than that of oxygen. This blocking of hemoglobin reduces the oxygen supply to the tissues; this situation is aggravated when combined with cardiovascular problems. Carbon monoxide may also display long term toxicity such as headache, dizziness and nausea, which occurs when CO blocks 25% of the hemoglobin. Loss of consciousness which is dangerous for drivers, can occur if the CO rate reaches 50% and death occurs when the rate reaches 70%

2.2 Hydro Carbons (Volatile Organic Compounds)

The oxidation speed of hydrocarbons at high temperature is very fast. So, except in some extreme cases of highly concentrated vapor, the HC, which is emitted in the exhaust, can be thought to be from some localized areas.

Because the walls of the combustion chamber are kept cool, flame propagation does not occur in a very thin layer of the vapor (unburnt gas layer) interfacing the wall, which remains unburned or partially combusted.

During the exhaust process this portion of the vapor, when it moves away from the wall, mixes with the warmer combusted gas, and if there is enough O_2 in the combusted gas a major portion undergoes oxidation. Also, if the temperature is sufficiently high the oxidation continues after leaving through the exhaust valves into the exhaust manifold.

The smaller the A/F ratio is, the lesser the O_2 and therefore the more the HC that will remain in the exhaust.

As the surface/volume ratio of the combustion chamber increases, the proportion of unburnt gas layer within the vapor also increases. Also, because of increased heat loss, the average temperature of the combusted gas also decreases and so the level of HC in the exhaust gas increases.

Unburnt gas layer is formed at the small hollows in the combustion chamber wall, and ‘top land’ (the area above the first piston ring) this also greatly affects the formation of HC.

In case of extremely lean vapor, flame propagation is slow and combustion may not complete by the time the exhaust valves open, or the flame may get put out completely. So, as lowest intensity driving levels are approached, the concentration of HC increases. Also, in case the vapor is extremely uneven, in some localized areas, delay of combustion may lead to formation of hydrocarbons. Large amount of residual gas or excessive turbulence in the vapor also lead to formation of unburnt gas layers in localized areas.

Effect of Hydrocarbons on health

Volatile organic compounds which are emitted from vehicles cause eye and respiratory irritation. Human heath is mainly affected by unstructured hydrocarbon. The olefins are liable to undergo partial metabolic conversion, converting them to genotoxic epoxides.

Monocyclic aromatic hydrocarbons

Benzene is well known haematoxic (casing blood poisoning) and occupational exposure to it can cause Leukemia. However this Leukemia only occurs with concentrations over 40 ppm. They affect the bone marrow by inhibiting the formation of red blood corpuscles. The WBC is also destroyed as well as the blood platelets. Benzene is a suspect in other hematological disorders such as Hodgkin's disease and lymphoma, and may cause chromosomal anomalies. The metabolites of benzene responsible for these biological effects are still poorly known, although phenols and epoxides are often mentioned as resulting from the enzymatic oxidation of benzene.

2.3 Nitrogen Oxides (NO_x)

The nitrogen oxide formed by the combining of N_2 and O_2 in the vapor, during combustion in the spark ignition engine. Nitric oxide (NO) is mostly formed with a small volume of nitrogen dioxide (NO_2). The emitted NO gets oxidized in the atmosphere and turns to NO_2. Usually NO and NO_2 are together referred to as NO_x.

The concentration of NO in the exhaust is strongly related to the maximum combustion temperature and the air-fuel ratio. Under constant volume combustion of the vapor, the equilibrium concentration level of NO in the combusted gas, in the case of no heat loss, is maximum when air-fuel ratio is 18. As the concentration of the vapor increases and the air-fuel ratio decreases NO level decreases rapidly. On the other side, as the concentration of vapor decreases, NO level also gradually decreases. However, as in the case of CO, the actual concentration of NO in the exhaust is much higher because the formation and decomposition speed of NO is much slower than the main speed of combustion.

Under theoretical calculations, because the initially combusted portion is at higher temperature for longer time, the formation of NO should progress in the combusted gas. Concentration of NO decreases as decomposition progresses with the expansion of the combusted gas above the optimum air/fuel ratio (i.e. lower concentration of vapor). However, the speed of decomposition is slow and the NO level does not reduce to the level expected with the decrease in temperature resulting in concentration level of NO emitted higher with the exhaust.

In lean vapor concentration NO formation is slow and does not reach the equilibrium level associated with the flame temperature. But because decomposition is also slow NO is emitted in the exhaust at an almost fixed concentration.

On the other hand, the later the combustion takes place, the lower the combustion temperature and the lesser the time spent in the combustion chamber. So, the NO formation is much less compared to the equilibrium level of the corresponding flame temperature. The NO emission gets fixed at this concentration and the NO contribution to the exhaust is small.

The concentration of NO in the exhaust is different than the equilibrium level associated with flame temperature. The concentration of NO is maximum when the air-fuel ratio is about 16 and decreases rather rapidly at vapor concentration levels lower or higher than this. The influence of the combusted gas temperature is extreme. At a constant air-fuel ratio, the equilibrium level of NO increases at an accelerating pace as the combusted gas temperature increases.

The formation of NO is facilitated by complete combustion whereas HC and CO result from incomplete combustion. The reduction in combustion gas temperature that would reduce NO formation would also lead to reduction in heat efficiency.

Formation of nitrogen oxides

Nitric oxide (NO) and nitrogen dioxide (NO_2) are usually grouped together as NO_x, in which NO largely predominates. The main source of NO is molar Nitrogen in air. The mechanism of NO formation from atmospheric Nitrogen in the neighborhood of stoichiometric ratio may be represented by chemical reactions. They, the main reactions leading to the formation of Nitric oxide (NO) are following.

$$O + N_2 \leftrightarrow NO + N \quad \text{\_\_\_\_\_\_\_\_\_\_\_} 1$$

$$N + O_2 \leftrightarrow NO + O \quad \text{\_\_\_\_\_\_\_\_\_\_\_} 2$$

$$N + OH \leftrightarrow NO + H \quad \text{\_\_\_\_\_\_\_\_\_\_\_} 3$$

The reaction no.3 as shown above takes place in a very rich mixture. NO is formed both in the flame front and in the gas leaving the flame. In engines, where combustion takes place under high pressure, the reaction zone in the flame is very thin and short-lived. Moreover, the pressure in the cylinder rises during combustion, with the effect of raising the burnt gases to a higher temperature than the one reached at immediately after combustion. This is why, except in the areas with a high fuel to air ratio, only a small part of the NO is generated in the flame and most of it is formed in the gases leaving the flame. Hence, the NO combustion and formation processes occur independently except with very high dilutions.

The reaction rate of formation of NO depends very strongly on the temperatures, and is slower than the combustion reaction, that is why concentrations measured in the exhaust are of non equilibrium values. The reaction rate of formation of NO is also highly dependant on the oxygen concentration. Accordingly high temperature and high oxygen concentration increase the NO produced.

Formation of nitrogen dioxide

The equilibrium calculations indicate that, in the burnt gases, with the temperatures routinely prevailing in the flames, the NO_2 concentrations should be negligible in comparison with NO. This is effectively the case in spark ignition engines. In diesel engines, however, up to 30% of the NO_x is found in the form of NO_2 [(4)]. One explanation of the persistence of NO_2 is that the NO formed in the flame can be converted rapidly to NO_2 by reactions of the type:

$$NO + HO_2 \leftrightarrow NO_2 + OH$$

$$NO_2 + O \leftrightarrow NO + O_2$$

Formation of nitrous oxide

In the gas phase nitrous oxide (N_2O) is a formed mainly from NH and NCO when they react with NO:

$$NH + NO \leftrightarrow N_2O + H$$

$$NCO + NO \leftrightarrow N_2O + CO$$

Hence this formation mechanism is limited to the oxidation zone. The hydrogen atom concentration there is always high and causes intense destruction of the nitrous oxide (N_2O) by the following reactions:

$$N_2O + H \leftrightarrow NH + NO$$

$$N_2O + H \leftrightarrow OH + N2$$

This is why the combustion of the premixed gas mixture in a, spark ignition engine emits very little nitrous oxide (N_2O).

Formation of nitrogen oxides in spark ignition engine

The most widespread spark ignition engine types are characterized by presence in the combustion chamber of a mixture of fuel and air, which is homogenized in the intake system during the intake phase. During the pressure increase caused by combustion, the concentration of NO formed in the burnt gas zones at high temperatures are fixed. However, when the temperature drops due to expansion, the concentration of NO rise to a value far above the equilibrium values corresponding to the values prevailed at exhaust.

Nitrogen oxides formation in spark ignition engine is largely affected by fuel: air ratio and temperature of combustion [(4)]. In lean mixtures, freezing occurs early in the expansion stroke and little NO decomposition occurs. With rich mixtures, freezing occurs later as compared to lean mixture and less NO decomposition occurs as a result, NO_X emissions are generally less sensitive to changes in engine operating conditions with rich mixtures then they are with lean mixture.

Effect of fuel /air ratio

The maximum temperature of the burnt gases correspond to an equivalence ratio of about 1.1 a slightly rich mixture. In these conditions, however, the O_2 concentration is low. As the equivalence ratio drops, the effect of increase in the O_2 partial pressure counter acts the temperature drops of the burnt gases, which tends to reduce the formation of NO. The NO emission peak thus appears for an equivalence ratio of about 0.9, which is slightly lean mixture. However if the excess air increases and the mixture becomes leaner to beyond the maximum NO the drop in the flame temperature reduces rate of formation of following reaction.

$$O + N2 \leftrightarrow NO + N \_\_\_\_\_\_\_\_\_\_ 1$$

$$N + O2 \leftrightarrow NO + O \_\_\_\_\_\_\_\_\_\_ 2$$

Effect of burnt gases fractions depends on the load, the valve settings, and particularly tontine valve overlap. A higher overleap increases the dilution of the feed and decreases the No emission. To a lesser extent; the residual gas fraction also depends on the engine speed, the Fuel: Air ratio, and the volumetric compression ratio. The reduction of the latter also causes a drop in NO emission.

The burnt gases act as diluents for the mixture. The temperature reached after combustion varies inversely with the quantity of burnt gases.

The significant reduction is achieved in emission up to 15 to 20% by EGR, a maximum permissible rate for an engine under partial load. However the best EGR must have lowest No emissions which is obtained at stoichiometric mixture either by carburetor or EFI system. The necessity of EGR to be compatible enough, i.e. not to deteriorate combustion quality it must be electronically controlled for optimal EGR percentage.

Effect of ignition timing

Under average engine speed and load conditions an advance reduction, on a mass produced engine, an advance reduction of 10 crankshaft degrees can cut NO emissions at constant power by about 20 to 30% as decrease in advance reduces the height of the pressure peak, because most of fuel burns after TDC.

Ignition advance causes combustion early in the cycle. Larger fraction of fuel is burned before top dead centre and pressure peak approaches TDC where the cylinder volume is smaller. This condition promotes the formation of NO.

Effect of nitrogen oxides on health

Nitrogen oxides produced during the combustion of fuel in the automobiles cause respiratory problems.

The nitric oxides NO is by itself nontoxic. The suspected effects concern its fixation to hemoglobin. The essential effect of NO stems from its role as a NO_2 precursor. Like carbon monoxide, nitrogen dioxide (NO_2) is also toxic and it binds to hemoglobin and decreases oxygen transport efficiency of blood and hence can cause lung disorders. It is insoluble and can penetrate deeply in to the pulmonary system. It acts on pulmonary alveoli and impairs their structures, inhibits the pulmonary defenses, and has a cytotoxic (any substance which is toxic to cells) effect on the alveolar macrophages. It stimulates their activity in low doses and then weakens the defenses of the body, thus causing other complications. Nitrogen peroxide can thus cause the death of specific cells in the lungs and impair the regulation of the pulmonary function. The symptoms of the toxic action of NO_2 are insomnia, coughing, panting, and impairment of the mucous membranes. Nitrogen dioxide (NO_2), which is more hazardous among the several forms of nitrogen oxides, causes one to exert greater efforts in breathing. It penetrates deep into human lungs causing edema. Human mucus membranes may feel irritation due to NO_x.

Photochemical smog is also linked to pollution from vehicles. Nitrogen oxides produced during the combustion of fuel in the automobiles cause contribute to photochemical smog. Smog contains oxidants such as ozone **(**O_3) and nitrogen dioxide (NO_2) and since Ozone is comparatively stable and it measured as an indication of air quality.

Ozone

The mechanism behind the formation of ozone may be represented by following chemical reaction.

$$NO_2 + \text{UV light} \rightarrow NO + O$$

$$O + O_2 \rightarrow O_3$$

The ozone formed depends on presence of nitrogen dioxide and ultraviolet light from sunlight.

Ozone displays toxic effects similar to those of NO_2, but in much lower concentration. However, its lower stability and greater solubility limit its depth of penetration. The human body reacts by shrinkage of the respiratory passages as soon as the O_3 concentration exceeds 0.1 ppm. Physical activity also diminishes tolerance to these pollutants. Other symptoms are irritation of the eyes and mucous membranes, headaches with coughing and reflexive inhabitation of breathing, as well as reduced lung capacity. O_3 can trigger attacks of asthma, followed by acute inflammation and pulmonary edema. Ozone strongly affects the pulmonary functions of asthmatics. Ozone causes oxidation of proteins and peroxidation of fatty acids, specially unstructured fatty acids. Anti-oxidation like vitamins E, can contract its action.

Sulphur Dioxide (SO_2)

Sulphur dioxides generally emitted from diesel vehicles, is another respiratory irritant. Sulphur in fuel is emitted as SO_2 in the exhaust gases. Sulphur is not only a direct threat to human health but also increase the emission particulates. Sulphur compound contribute to the volume of particulate matter which is one of major concerns. Particulate sulphur i.e. sulphuric acid (H_2SO_4) particles may act as condensation nuclei or cause visibility degradation. High concentration of SO_2 can give rise to human health effect which are respiratory in nature and aggravate bronchitis and can impair lungs function by constricting airways and damaging the tissues. SO_2 can cause severe damage to lung tissues following chronic exposure, accentuating pulmonary diseases and cardiac disorders. Very young and old people are most susceptible to these effects.

Environment affects include toxicity to plants either by direct gaseous toxicity or by acid deposition. The latter can make water system acidic damaging aqueous life. Corrosion of buildings, stone works and metals increases in presence of SO_2.

2.4 Suspended Particulate Matter (SPM)

Increasing lead and benzene pollution from vehicles also pose great threats to the health of the people. SPM emitted from the vehicles in the form of suspended particulate mater gets easily absorbed in brain, liver, kidney and blood which becomes cumulative poison over years, leading to brain damage, muscular paralysis and convulsions. Benzene is one such chemical belonging to this group of chemicals, higher doses of benzene lead to Leukemia.

The fine particles penetrate deep into the lung as for as the alveoli. Long term inhalation exposures to high level of diesel exhaust causes an increase in the induction of lung tumours. Short term exposure to high concentration of PM includes acute respiratory morbidity and decrement in lung functions, feeling of discomfort, annoyance and impairment of visibility. PM results in soiling, of exposed surfaces.

Aldehydes And Ketones

Aldehydes and Ketones are categorized as non-regulated pollutants.

Aldehydes

The factors responsible for formation of aldehydes includes flame quenching, slow combustion at lower temperature, variations in fuel / air ratio. Aldehydes essentially appear in a lean mixture due to incomplete oxidation of the hydrocarbons. This effect of fuel /air ratio is clearly demonstrated in the case of methanol fuel. The Aldehydes are mainly formed in the expansion stroke during the mixture of the warm air with the unburnt HC present on the walls in the quenched layer.

The RO_2 radio undergoes hydrogen migration, followed by decomposition to a hydroxyl radical and Aldehydes.

$$RCH_2OO \Rightarrow RC\ HOOH \Rightarrow RCHO + OH$$

The alcoxy radical RO formed during the thermal decomposition of a peroxide of the, ROOH type gives an aldehyde in the case of secondary radical by splitting of a C-C bond.

$$RR'CHO \Rightarrow RCHO + R$$

Ketones

Following reaction represents formation of ketones, which takes place in the process combustion of an engine.

$$RR'CHOO \Rightarrow RC\ OOH \Rightarrow RR'C \Rightarrow O + OH$$

It takes immensely less quantity for these compounds (non-regulated pollutants) to promote the development of lung cancer.

NORMS TO CONTROL VEHICULAR POLLUTION

The automobile has come a very far way since its first true development in the beginning of the 20^{th} century by Henry Ford. Our society has used technology in order to help advance to make it better and more efficient.

We have always had a need for speed, a need to have the best of the best, and a need to have the newest trend. And that is what major automobile industries have been giving our society because they know that they can profit greatly from it. These industries know what sells and they take advantage of it. In order to improve automobiles so that they meet these needs of our society, automobile industries turn to technology. Of course with this technology comes a flaw the biggest and most obvious flaw is pollution. Because of pollution, we find ourselves asking the question of whether this technology has helped our society more than it has hurt it. And now that we have identified the problem, how can it be fixed, and how will fixing the problem of automobile pollution affect society?

The following sections describe norms adopted for various components of emissions from different mode of engines as answers to the questions rose in preceding paragraph.

Emission norms

Emission norms are prescribed CO (Carbon monoxide), HC (Hydrocarbons), NO_x (Nitrogen oxides) and other pollutant's limits set by the government, which a vehicle should emit when running on roads. All the manufacturers need to implement the same for vehicle being manufactured from the date of implementation.

International emission standard for vehicular emission fall into following three categories.

1. European Emission system (Euro system)

2. Japanese Emission system.

3. American Emission system.

The European Emission system (Euro system) is followed by most of the countries, including India. Euro norms refer to the permissible emission levels from both petrol and Diesel vehicles, which have been implemented in Europe. They are the norms for regulating vehicular emission in Europe expressed in terms of the weight of the pollutants such as carbon monoxide (CO), hydrocarbons (HC) oxides of nitrogen (NO_x) and particulate matters (PM) emitted per kilometer of vehicular run. These ceilings have been fixed for various categories of vehicles; for instance, there are particular emission levels for petrol driven and diesel driven vehicles. Progression of Euro norms for gasoline fuelled passenger cars in Europe and India are described in table 3.1 below.

Table 3.1: **Progression of Euro Norms for Gasoline Fuelled Passenger Cars in Europe**

Description	**Effective year of implementation**		**Carbon Monoxide (g/km)**	**Hydro-Carbon (g/km)**	**Nitrogen Oxides (g/km)**	**Hydro-carbon + nitrogen oxides(g/km)**
	Europe	**India**				
Euro I	1993	2000	2.72	—	—	0.97
Euro II	1996	2005	2.20	----	---	0.50
Euro III	2000	2010*	2.30	0.20	0.15	—
Euro IV	2005	Not specified	1.00	0.10	0.08	—

***Preferably by April 1, 2008 but not latter than April 1, 2010

Source: www.petroleum.nic.in

The Euro norms

The Euro norms require manufacturers to reduce and the existing polluting emission levels in a more efficient manner by making certain technical changes in their vehicles.

Euro I and Euro II norms regulate vehicular emission in terms of the weight of the pollutants such as CO, hydrocarbons, NO_X and SPM emitted per km of vehicular run. Upper levels are fixed for different categories of vehicles and there are different emission levels for petrol and diesel driven vehicles.

Euro I norms in India are known as India 2000 since they were implemented from 1/4/2000 the norms equivalent to Euro II emission norms are called 2005 norms. The Euro I norm were implemented from the year 2000, Euro II emission norms are due to be implemented in 2005, the above Euro I norm were applicable from 1st JUNE 1999 only in the NCR (Delhi) as per the Supreme Court ruling and the Government Regulations and Euro II norm were implemented to NCR from 1st April 2000. The Euro I norm were implemented in Mumbai from January 1, 2000 while the Euro II emission norms were implemented in Mumbai from 1st APRIL 2000.

As per recent announcement by government of India the new vehicles in 11cities of India including Delhi (where vehicles presently conform to Euro II emission norms) will have to conform to Euro III emission norms April 1, 2005. The rest of the country will have Euro III emission norms preferably by April 1, 2008 but not latter than April 1, 2010.

The key to Euro I compliance is the strict maintenance of the air/fuel ratio in the engine, which is 15:1 in all cars. However, in an engine with carburetor fuel supply system, such as in all earlier domestic models, there is little control over the ratio. If there is an excess emission of carbon monoxide, or the oxides of nitrogen, their conversion into less noxious end products is left to the catalytic converter where a coating of noble metal helps catalyze the changes.

Changes for having a Euro I compliant vehicle

The following changes normally were made by manufacturers in order to have pollutant emission with in Euro I Norms applicable.

- Carburetor tuning
- Secondary air intake
- Exhaust gas Recirculation
- Catalyzing capacity increase
- Trimetal coating in the catalyser

Changes for having a Euro II compliant vehicle require that the carburetor be replaced by an MPFI system i.e. a Multi-point Fuel Injection System. Larger cylinders which need more fuel require more than one injector, thus resulting in a multi-point fuel injection system

Changes for having a Euro II compliant vehicle

Changes for having a Euro II compliant vehicle require that the carburetor be replaced by an EFI system i.e. a Multi-Point Fuel injection system. Other requirement to conform to Euro II norms are as follows

- Sophisticated engine tuning system
- Optimized catalyst formulation
- Continuous increase in the number of multi-valve engines
- Recirculation of the exhaust gas on certain vehicles

- Reduction in the percentage of benzene content in gasoline to go a maximum limit of one per cent

The large no. of vehicles which were registered after 31.03.2000 are Euro II norms compliant and are fitted with necessary MPFI systems.

Changes for having a Euro III compliant vehicle

For gasoline cars, the adoption of Euro III standards would require the following.

- Generalization of sequential MPFI
- Exhaust gas recirculation systems for the entire range
- Cold-phase management systems (start-up catalyst, catalyst heater, etc.)
- Increase in canister size for the recovery of evaporated gas
- A multi-valve strategy for almost the entire range
- A variable-intake or valve-number management strategy
- Introduction of OBD (onboard control systems) for engine operation control

The European Union proposes to implement Euro-IV norms from the year 2005 for which auto fuel specifications and technologies are yet to be finalized and evaluated. The committee deliberated on the suggestion for adoption of Euro-IV vehicular emission norms and the corresponding auto fuel quality. This route may offer certain advantage from environmental point of view as also in terms of an achievement of bringing the latest vehicle technologies and auto fuels in the country by leap frogging from the present Euro-I/Euro-II equivalent levels straight to Euro-IV level.

In an attempt to bring down emission levels in major cities, the government has decided to introduce Bharat stage-II norms, the Indian equivalent of Euro-II, in eight more cities across the country. The cities identified for introduction of stricter emissions norms include Ahmedabad, Banglore, Calcutta, Chennai, Hyderabad, Lucknow, Mumbai and

Poona. These norms were brought into operation in the national capital region (NCR) from 1st April, 2000.

Euro norms: Euro I and Euro II

The following are the various emission levels adopted for Euro I and Euro II norms in tabulated form.

TABLE 3.2 Euro I Limit

CO (carbon monoxide)	2.72 gm /km may be relaxed to 3.16 gm/km
HC's and NO_x	0.97 gm/km tolerated up to 1.13 gm/km.
Evaporative emissions	2gm/test at any stage.

TABLE 3.3 Euro II Limits

Carbon monoxide (CO)	2.2 gm/km (petrol) and 1gm/km (diesel)
H C's and NO_x	0.5 gm/km(petrol) and 0.7 gm/km(diesel)
Particulates	0.08 gm/km
Evaporative emissions	2gm/test (petrol cars)

India and Euro standards

The air pollution act 1991 is the first piece of legislation made in this regard. The permissible level of gaseous automobile exhaust emissions was tightened in 1996. India followed the European pattern for the emission norms. For commercial vehicle with diesel engines, the norms are based on the European legislation.

From April 1st 2000 these emission standard were implemented for the entire vehicle manufactured on or after that date for the National capital territory (NCT) of Delhi.

TABLE 3.4 Limits for Type Approval and Conformity of Production Tests

POLLUTANTS	LIMITS FOR TYPE	CONFORMITY OF
CO(g/kWh)	4.5	4.9
HC(g/kWh)	1.1	1.23
NO(g/kWh)	8.0	9.0
PM(g/kWh) for engine with Power exceeding 85 kw	0.36	0.4

The diesel version of vehicle as per Euro norms are expected to limit emission up to 1/2 times carbon monoxide and one fourth value for nitrogen oxides (NO_x) than the previously stipulated levels. Emission norms have also been set for particulate matter.

The introduction of Euro I and Euro II norms and vehicles fitted with devices such as catalytic converters and EFI system i.e. a MPFI system has switched over environment to its new healthy version.

The comparative statements of Indian norms applicable before and after year 2000 for small petrol driven car (with catalytic converters and cold start) are listed below.

Indian norms for the year 1998 (equivalent to their comparable European stringencies of ECE 83 year 1992) are represented in TABLE 3.5

ABLE 3.5 Indian Norms for the Year 1998

arbon monoxide (CO)	4.34-6.2 gm/km
Hydrocarbons + Nitrogen oxides (HC + NO_x)	1.5-2.2 gm/km

Indian norms for the year 1999-2000 and onwards (Euro I equivalent to their comparable European stringencies of ECE year 1994) are represented in TABLE 3.6

TABLE 3.6 Indian Norms for the Year 1999-2000 and Onwards

POLLUTANTS	Euro I	Euro II
Carbon monoxide (CO)	2.72 gm/km	2.20 gm/km
Hydrocarbons+ Nitrogen oxides (HC + NO_x)	0.97 gm/km	O.50 gm/km

The industry has acquired, developed, and adapted new technology, and reengineered itself to produce increasingly cleaner vehicle- Low Emission Vehicles (LEV) in 1996, and Ultra Low Emission Vehicle (ULEV) by 2000. The total emission has come down during the control period, from new vehicles i.e. emission from (ECV), Low Emission Vehicle (LEV) and Ultra Low Emission Vehicle (ULEV). The imposition of Euro norms in India has greatly helped in reducing environmental pollution. Petrol driven four wheeler vehicles which adhere to Euro norms, depending on its engine capacity, would emit 1/3 to 1/2 times carbon monoxide and 1/4 to 1/3 times hydrocarbons and nitrogen oxides than the previously stipulated levels.

DELHI’S VEHICLE POPULATION HISTORY

Delhi, the heart of the country is very much plagued today by environmental degradation. Ever since the declaration of Delhi as national capital City in 1911, there has been a steady influx of people from every nook and corner of the country. Rise in population and growth in economic activity has led to increase in pollution in Delhi. In Delhi, in 1971, there were only 2 lakes registered vehicles, which have now crossed 3.5 million marks, which is more than the combined vehicular population of Mumbai, Chennai and Calcutta. In 1975 the vehicular population in Delhi and Mumbai was about the same; today Delhi has approximately three times more vehicles than Mumbai. Delhi is the metropolitan city where commuters are primarily dependent on a single transport system, road. This has led to an enormous increase in the number of vehicles with the associated problems of traffic-congestion and increase in air pollution.

Delhi residents cannot afford to pay even the low, subsidized fares. Consider that a single one-way bus fare for people living on the outskirts of the city is $0.20-$0.25 (Rs.8 to Rs.10), depending on the number of transfers. For the poorest 28 percent of households with monthly incomes of less than Rs.2, 000 (about US $40), a single worker would spend 25 percent or more of their entire income on daily round trip bus fare. For those with incomes much less than Rs 2,000, the already low bus fare is prohibitively expensive. One market response, at the bottom of the service scale, is privately operated, indigenously designed auto rickshaws and four-wheel vehicles (sometimes referred to as jeeps) with 8 to 12 seats. These vehicles comprise an estimated 3 percent of the total vehicle fleet.[16] they operate without a schedule and sometimes without a fixed route. They are required to register with the Transport Authority, which requires meters to measure distance and fares, but many are known to evade these requirements. The vehicles are generally highly polluting, inefficient and noisy. They do not adhere to safety and emission standards and very little effort has been made to improve them

Delhi's registered vehicular population has nearly doubled to 4.5 million from 2.2 million in 1994, registering a growth rate of 10% per annum. About two-Third of the Motor Vehicles are Delhi is expected to continue growing at a rapid rate into the foreseeable future. Its population is expected to surpass 22 million by 2020, and motor vehicles are expected to grow at an even faster rate. The domestic auto industry is predicting car sale increases of ten percent per year. With an extensive network of roads and increasing income, this sharp upward trajectory in vehicle sales and use is plausible.

Like most mega cities of the developing world, Delhi is not prepared to manage this pent up demand. If the present trends of vehicle population continue to grow, Delhi may face extreme economic and environmental consequences. Air pollution increasingly threatens human health; road traffic could worsen to the point of paralysis, large settlements of poor people on the urban periphery may become even more disenfranchised, and the cost of doing business and providing.

The growing vehicle population and high emission rates have lead to serious air pollution and health effect problems. This high level of vehicle ownership indicates that personal vehicles can play a large role in urban transport at very low-income levels. Although average per capita income is about 35 times less than that of the United States, most Delhi households own a personal vehicle. About two thirds of these vehicles are low-powered and highly inefficient mopeds, scooters, and motorcycles, with 50-150-cc engines costing $400 to $1,200. Used two-wheelers (and many used cars) cost even less. While neither comfortable nor reliable, two-wheelers provide convenient, inexpensive travel.

The entire vehicle fleet motorized and non-motorized is growing rapidly. From 1975 to 1998, the car population increased from about 68,000 to almost 800,000, and motorized two wheelers from about 100,000 to almost 2 million. With continued income growth, the motor vehicle population is expected to continue expanding at a high rate (Table 4.1).

Table-4.1. Growth Of Vehicular Population In Delhi (Base Yr 1971)

Year	Population (Million)	No of vehicles (Millions	Road length (Km)	Density (Veh/Km)	Density (Veh/1000 person)
1971	4.07	0.18	8380	21.48	44.27
1981	6.22	0.52	14316	36.39	83.76
1991	9.42	1.81	21564	84.08	192.44
2001	13.78	3.46	28508	121.26	250.82
2006	17.28	4.6	32317	142.3	266.20
Growth	4.24	25.55	3.85	6.62	6.01

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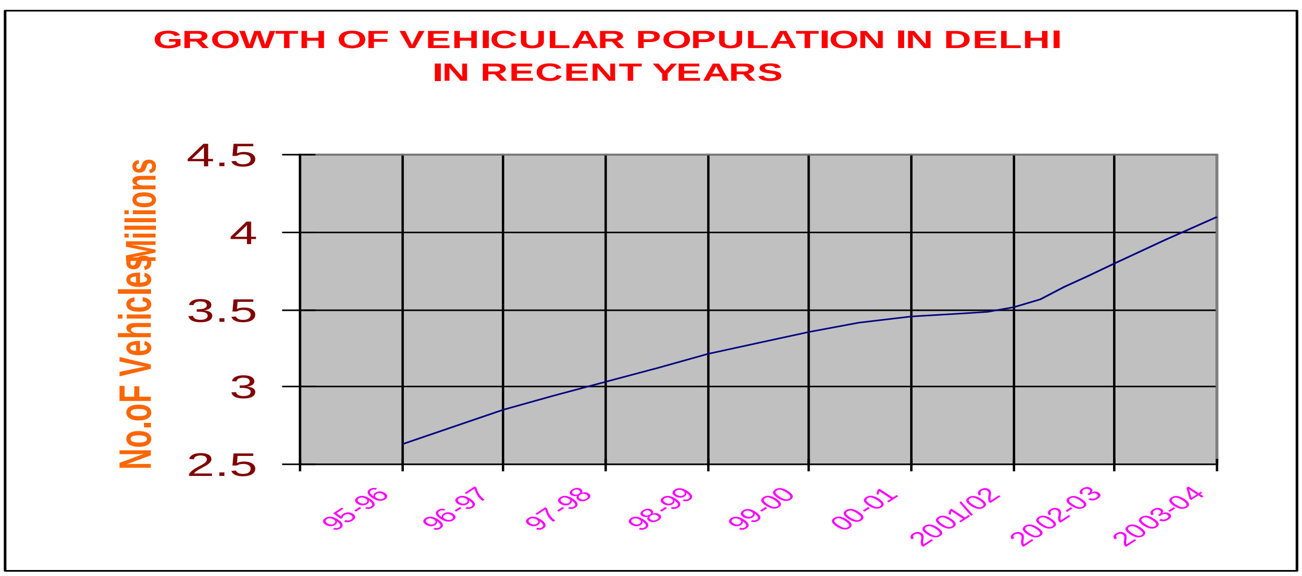
Figure 4.1 Growth of Vehicle/ Population in Delhi (Base year 1971)

Table 4.2. Vehicular Growth during 1995 To 2002 Years In Delhi

Year → Type. Of Vehicles ↓	95-96	96-97	97-98	98-99	99-2000	2000-01	2001-02
Cars and Jeeps	*633802*	705923	765470	818962	869820	957925	1047048
Scooter and M/Cy.	1741260	1876053	1991710	2101876	2184581	2199051	2339923
Auto Rickshaw	79011	80210	80210	86985	86985	86985	86985

Taxies	13765	15015	16654	17136	17762	18362	20628
Buses	27889	29572	32333	35254	37733	41483	12302
Goods Vehicle	133918	140922	146668	150243	156157	158492	161650
Total	2629645	2847695	3033045	3210456	3353038	3456479	3516414



Passenger Travel

The number of bicycles and cycle rickshaws is also very large and increasing, though the number is unknown since many owners do not comply with the requirement for annual registration. Current policies regarding cycle rickshaws and other non-motorized vehicles are restrictive based on the notion that efficient ("modern") transport systems do not include these vehicles. Traffic management experts and traffic police have proposed area and time restrictions on the movement of cycle rickshaws in Delhi. The number of cycle rickshaws that can be registered in the city is fixed at 99,000. Not surprisingly, a large number of cycle rickshaws are unregistered. We estimate that as many as 300,000 cycle rickshaws currently travel on Delhi roads. Buses form the backbone of the transport system in Delhi. Generally, buses are the most economically and environmentally efficient means of providing transport services to most people. In Delhi, buses constitute less than one percent of the vehicle fleet, but serve about half of all travel demand. Since 1992, Delhi has turned increasingly to the private sector to help expand and improve bus service. This decision was a response to the widely acknowledged shortcomings of public bus service, including escalating costs, poor maintenance, high labor costs, an aging bus fleet, and erratic service. Bus service was expanded in 1996 by adding more buses, with buses per route increasing from 0.8 to 1.7. The regular fixed-route bus system now comprises about 4,000 privately operated buses and 3,760 publicly operated buses. It is complemented by 5,000 private charter buses that provide point-to-point service during peak hours to subscribers who pay a monthly fee for a guaranteed seat.[14] Public buses provide a low level of service and comfort, with passengers often traveling on footboards and bus roofs. Large-scale privatization has increased capacity but buses continue to be overcrowded and poorly maintained. Although buses carry half of all passenger travel, they receive no preferential treatment in terms of dedicated lanes or traffic management. The low quality of service is due largely to the extreme poverty of so many riders. Many Delhi residents cannot afford to pay even the low, subsidized fares. Consider that a single one-way bus fare for people living on the outskirts of the city is $0.20-$0.25 (Rs.8 to Rs.10), depending on the number of transfers. For the poorest 28 percent of households with monthly incomes of less than Rs.2, 000 (about US $40), a single worker would spend 25 percent or more of their entire income on daily round trip bus fare. For those with incomes much less than Rs 2,000, the already low bus fare is prohibitively expensive. One market response, at the bottom of the service scale, is privately operated, indigenously designed auto rickshaws and four-wheel vehicles (sometimes referred to as jeeps) with 8 to 12 seats. These vehicles comprise an estimated 3 percent of the total vehicle fleet.[16] they operate without a schedule and sometimes without a fixed route. They are required to register with the Transport Authority, which requires meters to measure distance and fares, but many are known to evade these requirements. The vehicles are generally highly polluting, inefficient and noisy. They do not adhere to safety and emission standards and very little effort has been made to improve them. The government of Delhi recently issued norms restricting the age of vehicles that can be used or sold new for commercially registered vehicles, but enforcement is spotty. An upper end market response is chartered buses, mentioned above. These private buses provide point-to-point service to individual subscribers, schools, and companies and are playing an expanding role in Delhi.[18] They accounted for 4 percent of total bus trips in 1982, increasing to 11 percent in 1997. Users are in roughly the wealthiest 15 percent of the population. These buses are in many ways in direct competition with personal vehicles. Indeed, 43 percent of the charter bus commuters own two-wheelers and 11 percent own cars. Charter buses are in many cases replacing the use, and perhaps even purchase, of private vehicles. Despite these expanded transit services, mass transit services continue to lose market share.

Table 4.3 Growth during 2000 To 2006 Years In Delhi

Types of vehicles	2000-01 During Cumulative		2001-02 During Cumulative		2002-03 During Cumulative		2003-04 During Cumulative		2004-05 During Cumulative		2005-06 During Cumulative	
1	2	3	4	5	6	7	8	9	10	11	12	13
Cars & Jeeps	84482	957925	89123	1047048	92705	1139753	104006	1243759	115514	1359273	112585	1471858

Motor Cycles & scooters	121465	2199051	140872	2339923	162561	2502484	156965	2659449	180389	2839838	238822	3078660
Ambulance	77	1498	132	1630	90	1720	137	1857	124	1981	107	2088
Auto Rickshaws	0	70145	1	70146	0	70146	3292	73438	750	74188	0	74188
Taxies	1059	9604	3294	12898	1969	14867	1366	16233	1904	18137	2509	20646
I. Buses	1467	16981	3522	20503	2314	22817	1256	24073	724	24797	714	25511
ii. Other	964	6577	2842	9419	3374	12793	1939	14732	1634	16366	2012	18378
Passenger vehicles												
Tractors	26	4621	35	4656	41	4697	68	4765	46	4811		
Goods Vehicles	2053	102982	2880	105862	5171	111033	5686	116719	5287	122006	6187	128193
Others	16	5795	8	5803	0	5803	0	5803	0	5803	0	5803
Total	211588	3375153	242700	3617853	268219	3886072	274688	4160760	306394	4467154	362982	4830136

Figure 4.3 **TYPE OF VEHICLES**

IN DELHI'S VEHICLE POPULATION

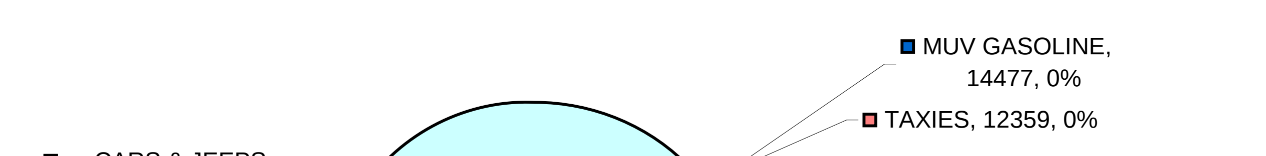


Table-4.4. Growths of Motor Vehicles in Delhi

Items	1990-91	1995-96	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
1	2	3	4	5	6	7	8	9
Number of Vehicles	1812967	2629645	3375153	3617853	3886072	4160760	4467154	4830136
Increase in number ofVehicles	1753	19735	211588	242700	268219	274688	306394	362982
Annual Growth (%)	10.71	8.11	8.05	7.19	7.41	7.07	7.36	8.13
Number of Vehicles per 1000 Population	192	231	244	254	265	270	282	295

Buses accounted for 57 percent of total passenger kilometers in 1990, dropping to about 49 percent in 2000. This drop is largely due to increased use of motorized personal vehicles in upper-income households (mostly two-wheelers but also cars), and the expanding population of very poor immigrants who cannot afford to ride buses.

Freight movement is a highly decentralized business activity; consequently, data are sparse and understanding of freight activity is poor outside each industry. It is clear that intra-city movement of freight is almost entirely by truck and increasing at a rapid rate. The volume of goods is forecast to increase fivefold from 1995 to 2006, and the number of freight vehicles four and a half times. Goods are carried by various vehicles, ranging from small three-wheelers for local deliveries to large tractor-trailers. The authors estimate that freight vehicles constitute only about 3 percent of all vehicles. However, freight vehicles outnumber buses five to one, and use about 11 percent of the transport energy consumed in Delhi. About one-fourth of total goods movements in Delhi are believed to be trans-shipments that originate elsewhere and pass through the city. Trans-shipments are mostly by rail. Many changes are occurring in urban freight operations. Most freight from outside Delhi enters by rail on the nation's extensive network, but trucks are quickly increasing the share of freight transport into the city. The National Planning Commission estimates freight traffic by road will increase from 807 billion tone-kilometers in 1997 to between 1,276 and 1,700 tone-kilometers by 2002. The transport of most grains, fruits, and vegetables has shifted to trucks and other road vehicles. These shifts from rail to truck imply more trucks passing through the city. The

Delhi government is considering a proposal to build a ring road around the city to divert these trucks away from the city. Renewed efforts to enhance the decaying rail system could stem this shift to trucks. Because demand for freight is growing faster than the economy and because trucks consume far more energy per tone-kilometer than rail, the net effect is rapid increases in energy use and greenhouse gases from the freight transport sector.

Type of Vehicle	1990-91	1995-96	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06

1	2	3	4	5	6	7	8	9
Cars & Jeeps	21.98	24.10	28.38	28.942	29.33	29.89	30.43	30.47
Motor Cycles & Scooters	67.32	66.23	65.15	64.68	64.40	63.92	63.57	63.74
Ambulance			0.04	0.04	0.04	0.04	0.04	0.04
Auto Rickshaws	3.48	3.00	2.08	1.94	1.8	1.77	1.66	1.54
Taxies	0.56	0.52	0.29	0.36	0.38	0.39	0.41	0.43
I. Buses	1.04	1.06	0.50	0.57	0.59	0.58	0.55	0.53
ii. Other Passenger vehicles			0.20	0.26	0.33	0.35	0.37	0.38
Tractors			0.14	0.13	0.12	0.11	0.11	0.10
Goods Vehicles	5.62	5.09	3.05	2.92	2.86	2.81	2.73	2.65
Others			0.17	0.16	0.15	0.14	0.13	0.12
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Unfortunately, there has been little research on how to enhance the delivery of goods in an economically and environmentally attractive manner. Population and income projections and on travel patterns of the past two decades, the model predicts that total motorized passenger travel would increase from 94 billion passenger-kilometers in 2000. This represents an 8.7 percent annual increase a somewhat faster rate than the 7 percent rate experienced in the 1990s.The major factors behind this rapid increase in travel are higher levels of per capita income, more people, overall economic growth, greater access to personal vehicles, and greater distances traveled per vehicle.

Table-4.5 Type of Motor Vehicles in Delhi as % Share

VEHICLE EMMISIONS LOAD CALCULATION

Vehicular emissions load in Delhi has been estimated as following:-

The numbers of vehicle registered with the department of transport, Govt. of NCT of Delhi were grouped in four different categories (during 1986-1990, 1991-1995, 1996-2000 and 2001-2006) as per the year of their registration. The details are shown in table no. 5.1 to 5.4.

The emission factors for different category (based on vehicle type, age, fuel used, technology etc.) were referred by the report of CPCB Delhi, INDIA.

The average kilometers traveled per day by that category of vehicle are taken from the report "Assessment of the PUC programme in India and recommendation for improvement "by John Rogers Grepo Trafalgar of Maxicocity.

The numbers of vehicle registered were multiplied by the emission factors for different category and the average kilometer traveled per day by that category of vehicle to obtain the daily pollution load of any pollutant.

The pollution load for Delhi comes out as following:-

Pollutant	Quantity in Tons Per Day
CO	448.26
HC	173.61
NO_x	132.39
PM	24.1

The figures in the form of pie charts no. 5.1 to 5.16 show shares of particular emission for different categories of vehicles. Where as figure 5.17 represent the overall growth OF vehicular population in Delhi with respect to base year 1971.

Type of Vehicle	NO.of vehicles	Avg. km.	CO		HC		NOX	
	Registerd	Travelled per year	Emission	Emission kg.	Emission	Emission .	Emission	Em
			Factor g/km		Factor	Kg.	Factor	Kg
2-WHEELER--2S	507446	10,000	6.5	32983.99	3.9	19790.39	0.03	15
2-WHEELER--4S	26708	10,000	3	801.24	0.8	213.664	0.31	8
3--WHEELER--2S	0	40,000	14	0	8.3	0	0.05	
CARS & JEEPS G	184279	15,000	9.8	27089.01	1.7	4699.115	1.8	49
CARS & JEEPS D	0	15,000	7.3	0	0.37	0	2.77	
TAXIES	0	30,000	9.8	0	1.7	0	1.8	
MUV G	3170	37,000	9.8	1149.442	1.7	199.393	1.8	2
MUV D	12681	37,000	7.3	3425.138	0.37	173.6029	2.77	12
LCV	17540	40,000	8.7	6103.92	0.34	238.544	3.15	2

TRUCKS	15908	30,000	5.5	2624.82	1.78	849.4872	9.5	4
BUSES	0	60,000	5.5	0	1.78	0	19	
				74177.56		26164.2		13

Table 5.1 Share Of Pollutants Load For Different Category Of Vehicles (1986-1990)

Type of Vehicle	NO.of vehicles	Avg. km.	CO		HC		NOX	
	Registerd	Travelled per year	Emission	Emission kg.	Emission	Emission .	Emission	E
			Factor g/km		Factor	Kg.	Factor	K
2-WHEELER--2S	466884	10,000	6.5	30347.46	3.9	18208.48	0.03	1
2-WHEELER--4S	37610	10,000	3	1128.3	0.8	300.88	0.31	
3--WHEELER--2S	16047	40,000	14	8986.32	8.3	5327.604	0.05	
CARS & JEEPS G	215007	15,000	9.8	31606.03	1.7	5482.679	1.8	5
CARS & JEEPS D	600	15,000	7.3	65.7	0.37	3.33	2.77	
TAXIES	2889	30,000	9.8	849.366	1.7	147.339	1.8	
MUV G	3000	37,000	9.8	1087.8	1.7	188.7	1.8	
MUV D	11999	37,000	7.3	3240.93	0.37	164.2663	2.77	1
LCV	17480	40,000	8.7	6083.04	0.34	237.728	3.15	
TRUCKS	15854	30,000	5.5	2615.91	1.78	846.6036	9.5	
BUSES	4220	60,000	5.5	1392.6	1.78	450.696	19	
				87403.45		31358.3		1

Table 5.2 Share Of Pollutants Load For Different Category Of Vehicles (1991-1995)

Type of Vehicle	NO.of vehicles	Avg. km.	CO		HC		NOX	
	Registerd	Travelled per year	Emission	Emission kg.	Emission	Emission .	Emission	Emis
			Factor g/km		Factor	Kg.	Factor	Kg.

2-WHEELER--2S	503000	10,000	4	20120	3.3	16599	0.06	3
2-WHEELER--4S	127825	10,000	2.6	3323.45	0.7	894.775	0.3	383
3--WHEELER--2S	14781	40,000	8.6	5084.664	7	4138.68	0.09	53.
CARS & JEEPS G	354488	15,000	3.9	20737.548	0.8	4253.856	1.1	5849
CARS & JEEPS D	10087	15,000	1.2	181.566	0.37	55.98285	0.69	104.
TAXIES	5464	30,000	3.9	639.288	0.8	131.136	1.1	180
MUV G	5599	37,000	6.9	1429.4247	0.28	58.00564	2.49	515.
MUV D	22398	37,000	2.4	19889.424	0.74	613.2572	1.38	828
LCV	22061	40,000	6.9	6088.836	0.28	247.0832	2.49	2197
TRUCKS	20009	30,000	4.5	2701.215	1.21	726.3267	8.4	5042
BUSES	9235	60,000	4.5	2493.45	1.21	670.461	16.8	930
				82688.8657		28388.56		2476

Table 5.3 Share Of Pollutants Load For Different Category Of Vehicles (1996-2000)

Type of Vehicle	NO.of vehicles	Avg. km.	CO		HC		NOX	
	Registerd	Travelled per year	Emission	Emission kg.	Emission	Emission .	Emission	Emis
			Factor g/km		Factor	Kg.	Factor	Kg.
2-WHEELER--2S	1087893	10,000	4	43515.72	3.3	35900.47	0.06	652.
2-WHEELER--4S	1990767	10,000	2.6	51759.942	0.7	13935.37	0.3	5972
3--WHEELER--2S	74188	40,000	8.6	25520.672	7	20772.64	0.09	267.
CARS & JEEPS G	533603	15,000	3.9	31215.7755	0.8	6403.236	1.1	880
CARS & JEEPS D	938255	15,000	1.2	16888.59	0.37	5207.315	0.69	9710
TAXIES	20646	30,000	3.9	2415.582	0.8	495.504	1.1	681
LCV	60208	40,000	6.9	16617.408	0.28	674.3296	2.49	5996
TRUCKS	67985	30,000	4.5	9177.975	1.21	2467.856	8.4	1713
BUSES	25511	60,000	4.5	6887.97	1.21	1852.099	16.8	2571
				203999.635		87708.82		7493

Table 5.4 Share Of Pollutants Load For Different Category Of Vehicles (2000-2006)

Figure 5.1 The CO Emissions from Various categories of Vehicles During 1986-1990 (Total Carbon Monooxide Emissions 74.17755 TPD)

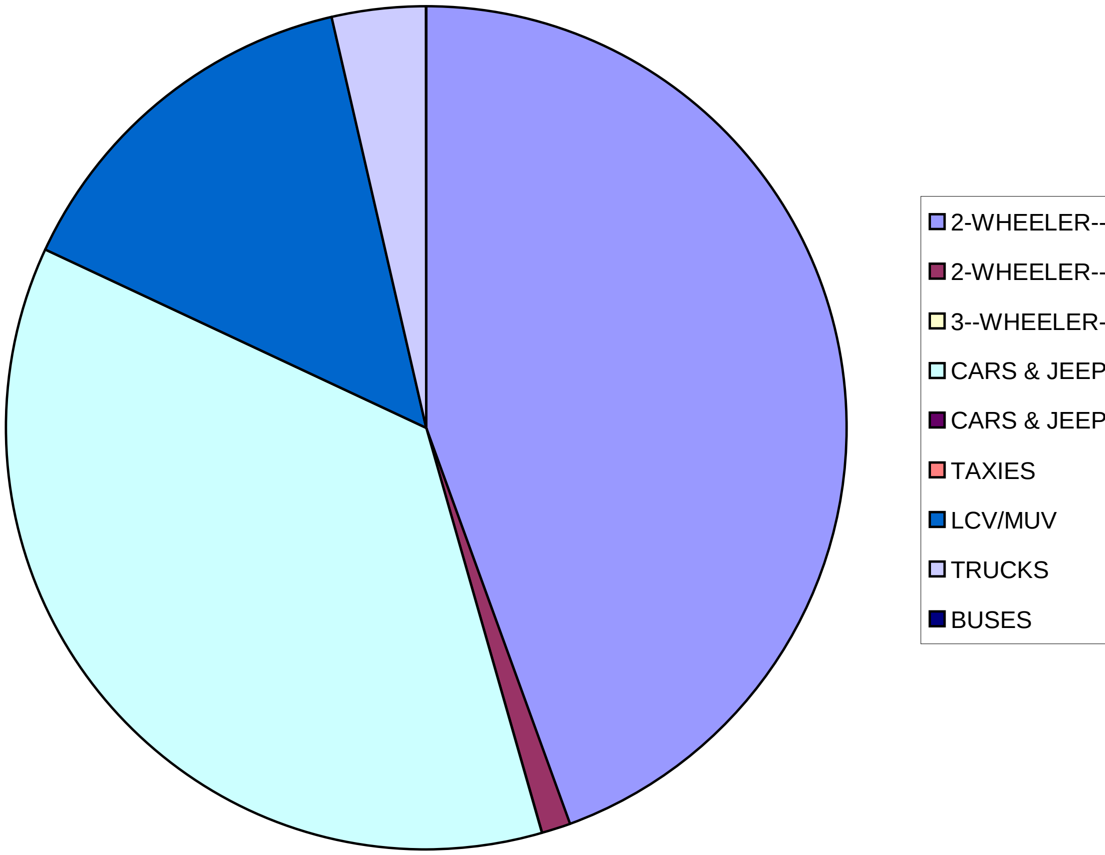


Figure 5.2 The HC Emissions From Various category of Vehicles During 1986-1990 (Total HC Emissions 26.1642 TPD).

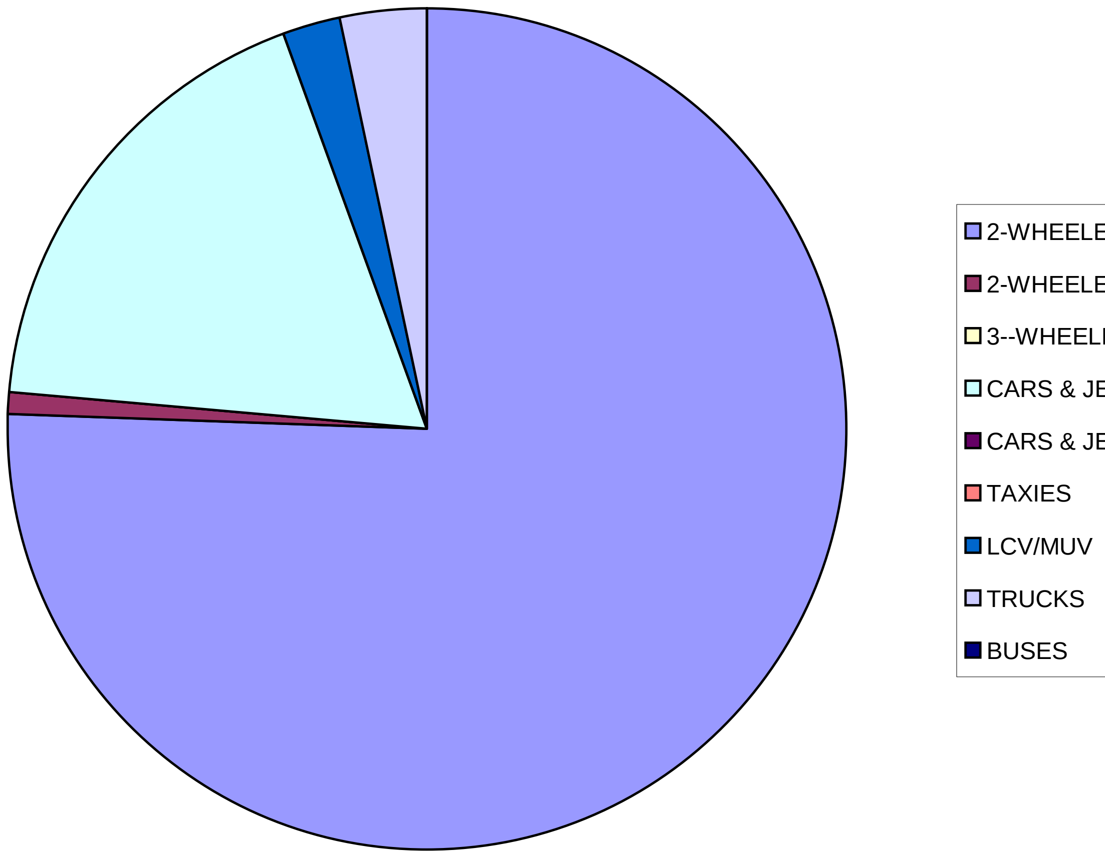


Figure 5.3 The NOx Emissions From Various category of Vehicles During 1986-1990 (Total NOx Emissions 13.46518 TPD)

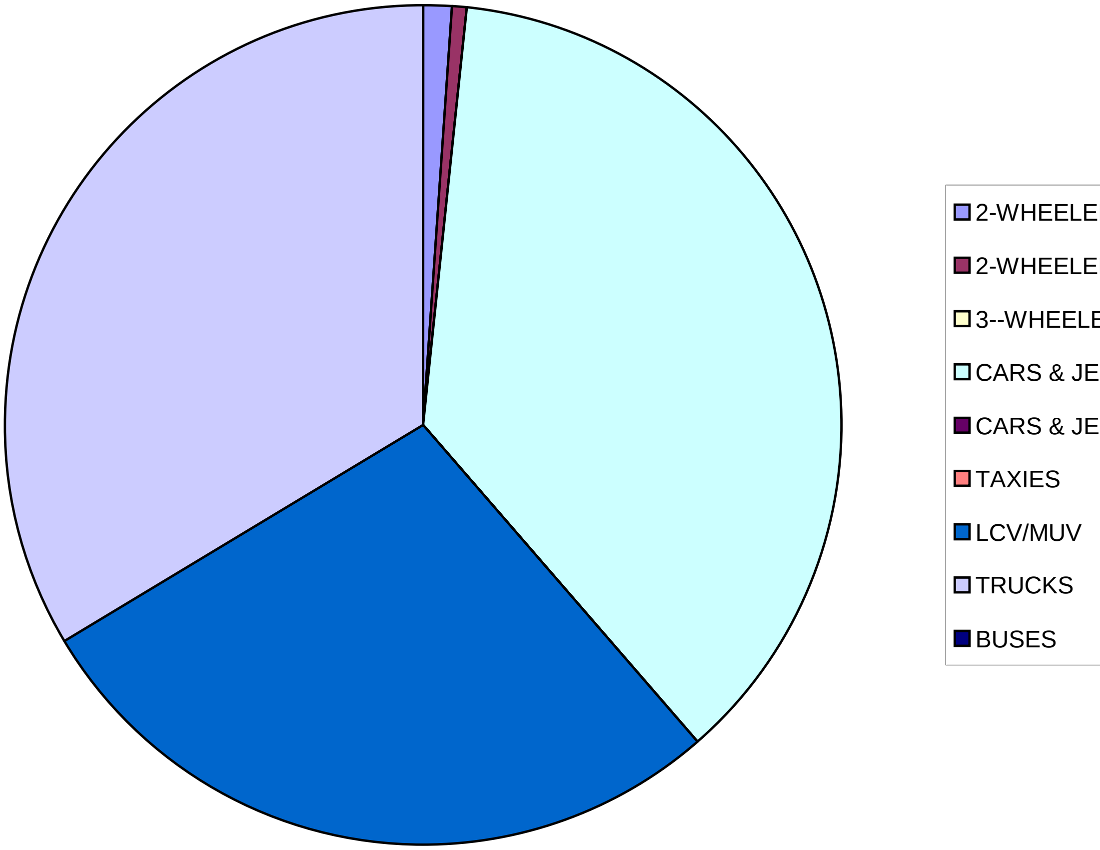


Figure 5.4 The PM Emissions From Various category of Vehicles During 1986-1990 (Total PM Emissions 30.2997 TPD)

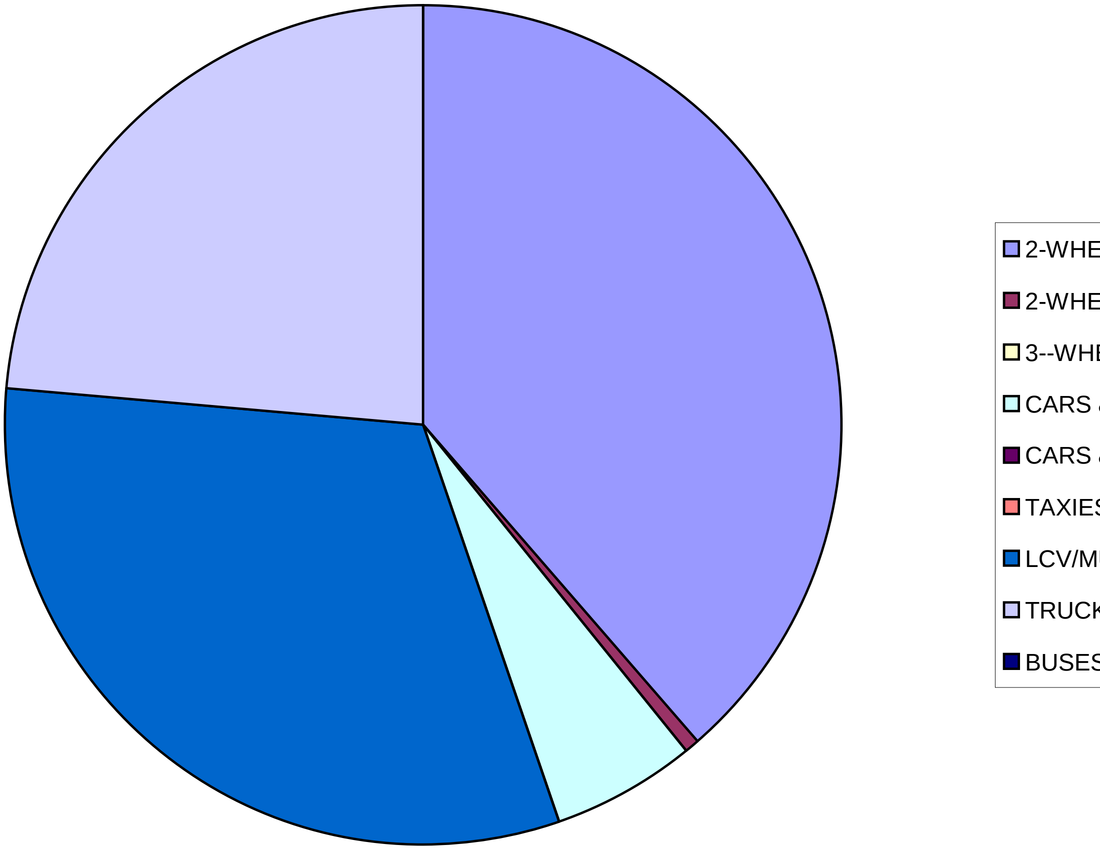


Figure 5.5 The CO Emissions From Various category of Vehicles During 1991-1995 (Total CO Emissions 87.403 TPD)

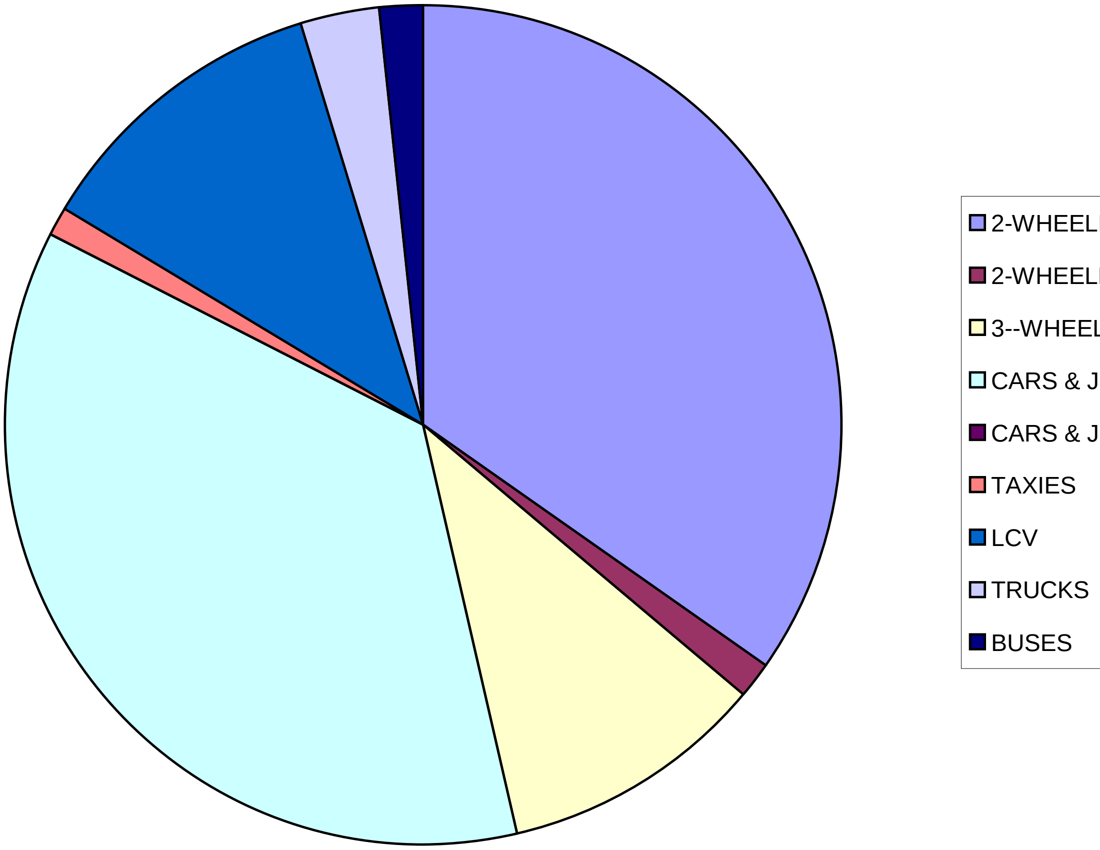


Figure 5.6 The HC Emissions From Various category of Vehicles During 1991-1995 (Total HC Emissions 31.358 TPD)

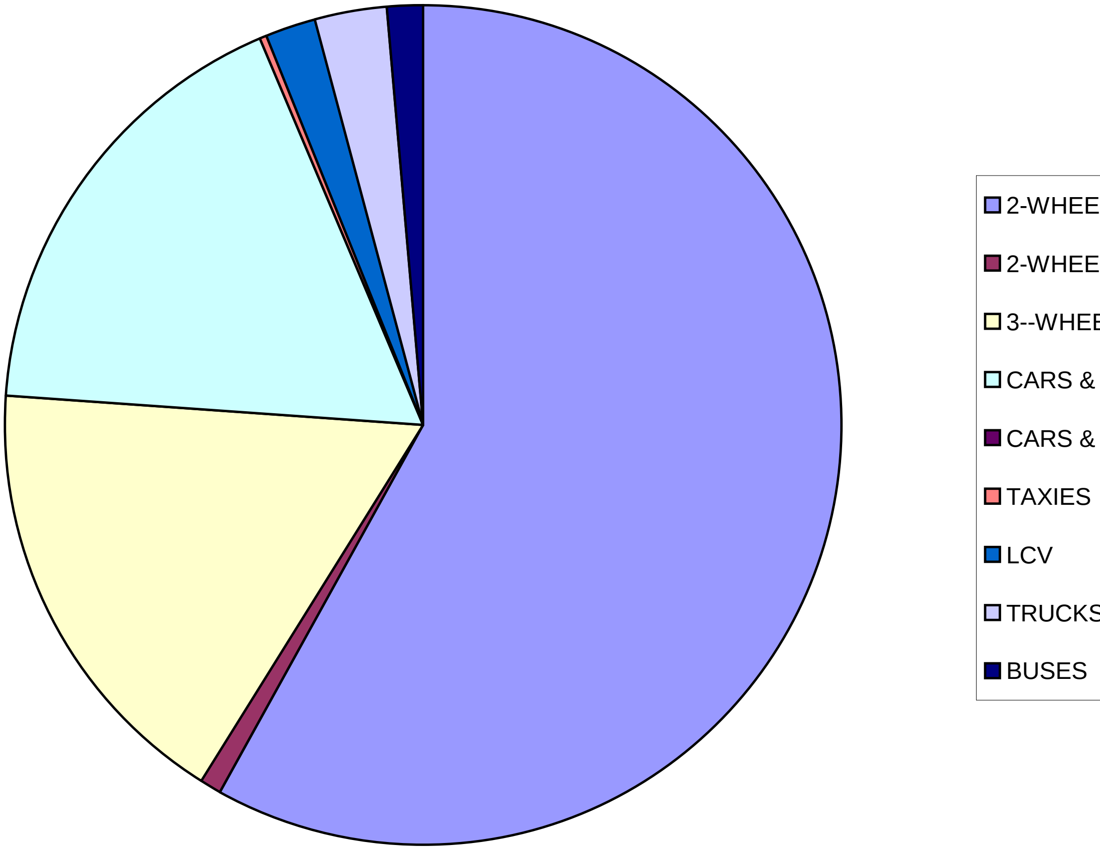


Figure 5.7 The NOx Emissions From Various category of Vehicles During 1991-1995

NOx Emissions 19.236 TPD)

(Total

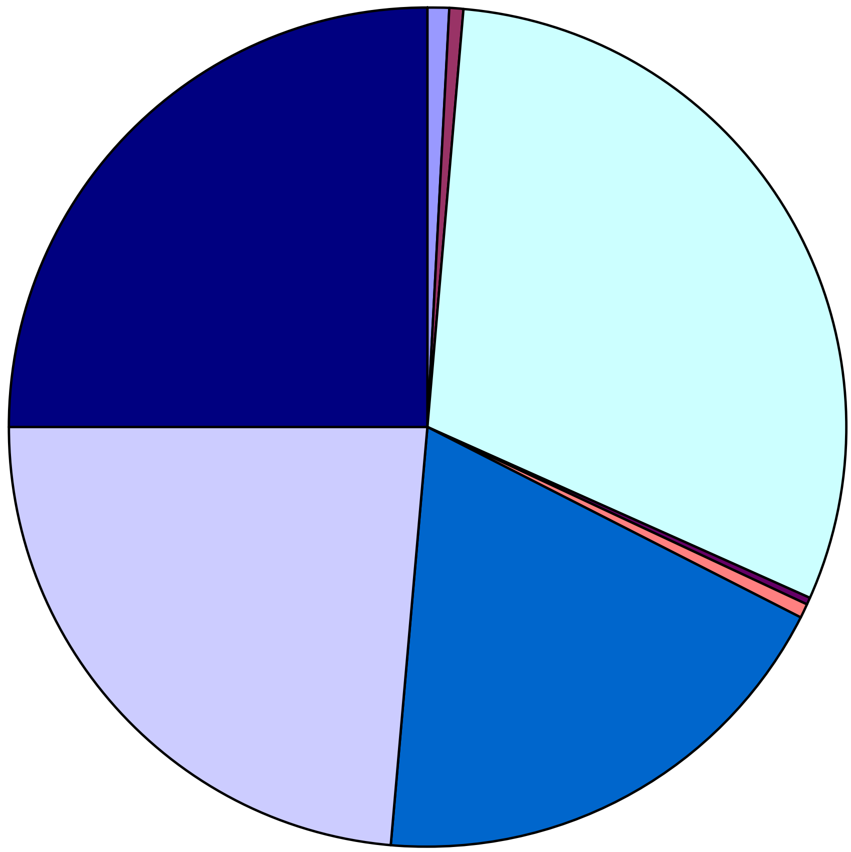


Figure 5.8 The PM Emissions From Various category of Vehicles During 1991-1995 (Total PM Emissions 39.4306 TPD)

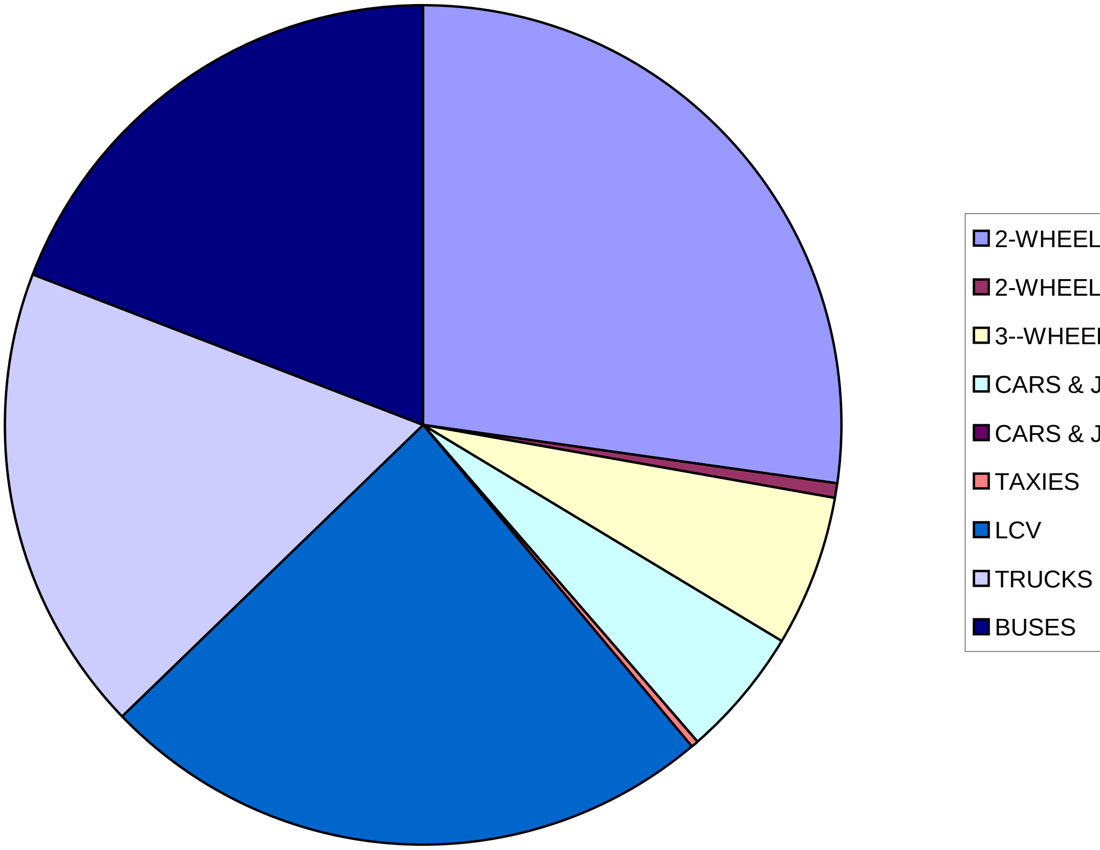


Figure 5.9 The CO Emissions From Various category of Vehicles During 1996-2000
(Total CO Emissions 82.6886 TPD).

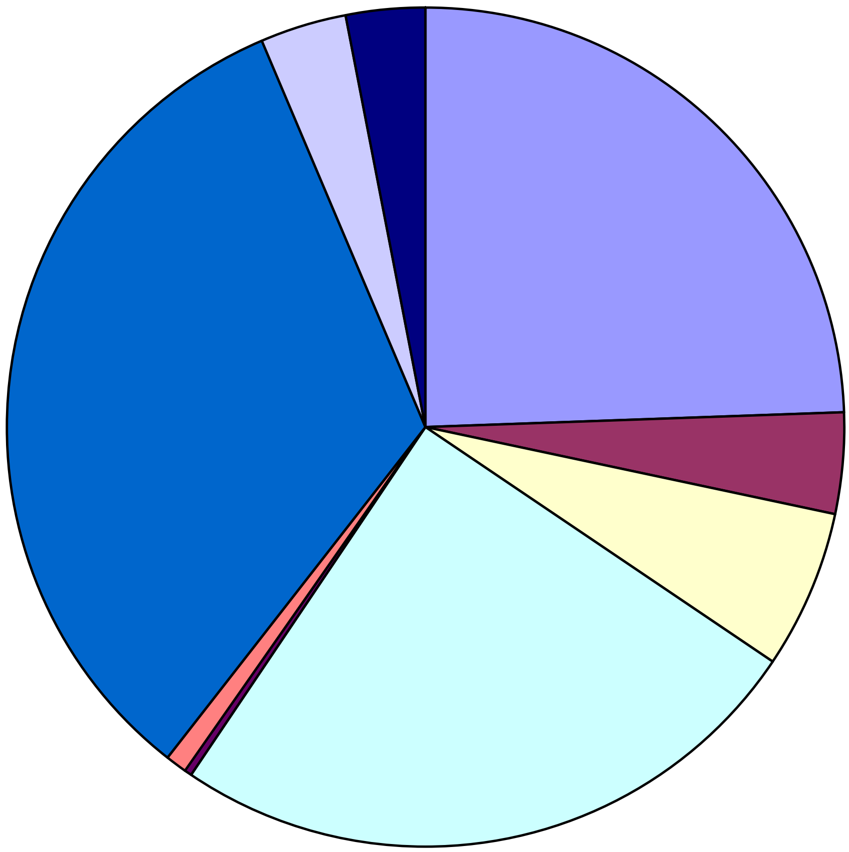


Figure 5.10 The HC Emissions From Various category of Vehicles During 1996-2000 (Total HC Emissions 28.3886 TPD)

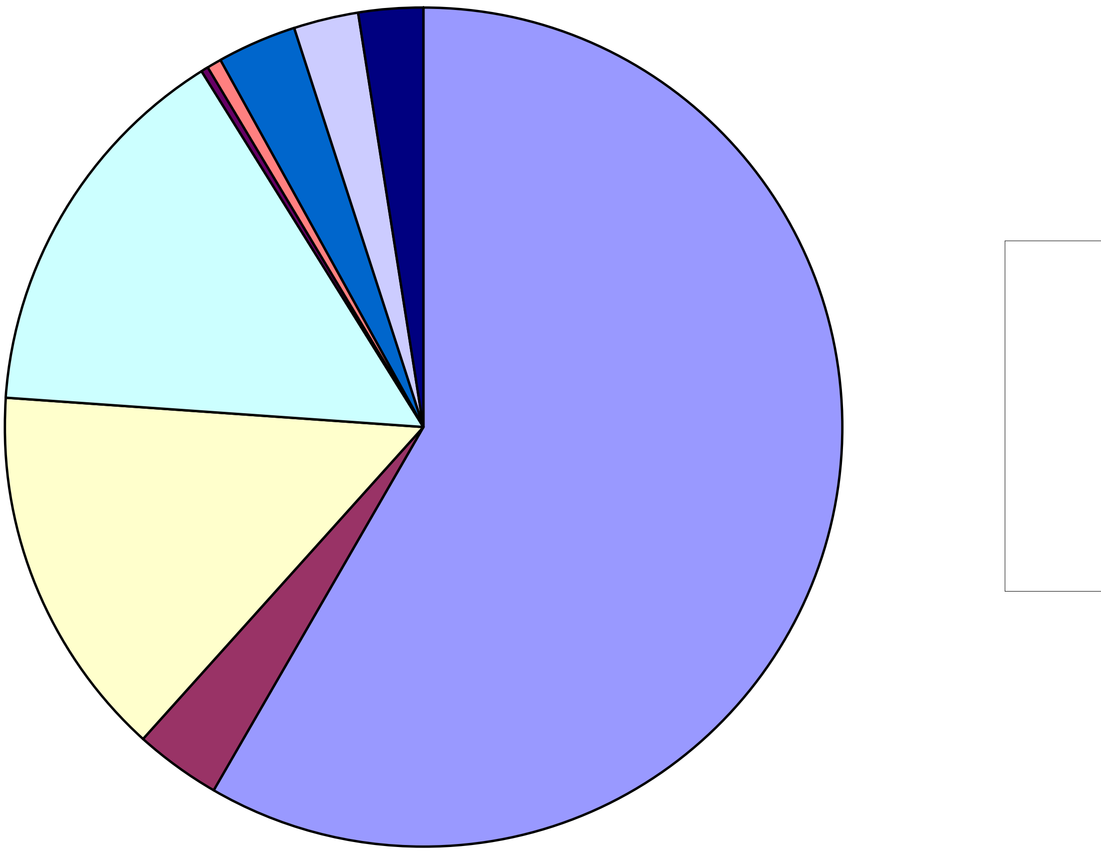


Figure 5.11 The NOx Emissions From Various category of Vehicles During 1996-2000 (Total NOx Emissions 24.765TPD)

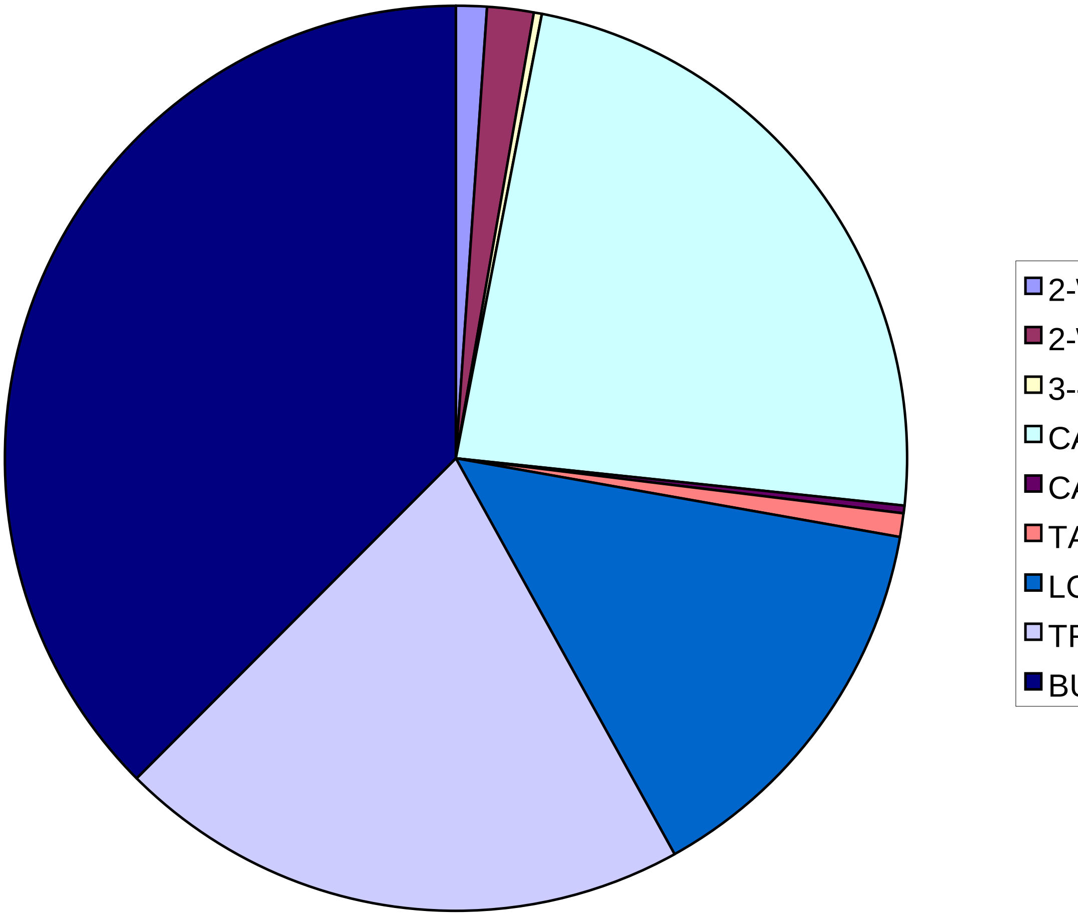


Figure 5.12 The PM Emissions From Various category of Vehicles During 1996-2000
(Total PM Emissions 3.613 TPD)

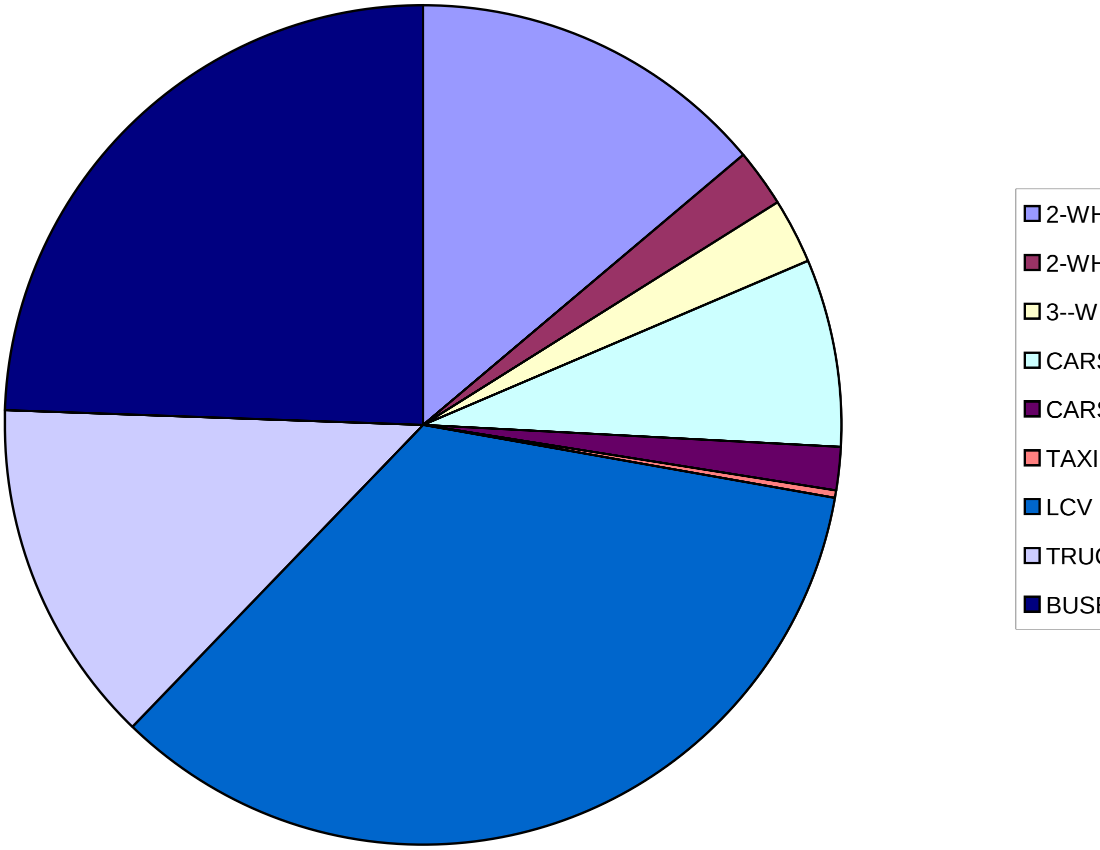


Figure 5.13 The CO Emissions From Various category of Vehicles During 2001-2006 (Total CO Emissions 203.99963 TPD)

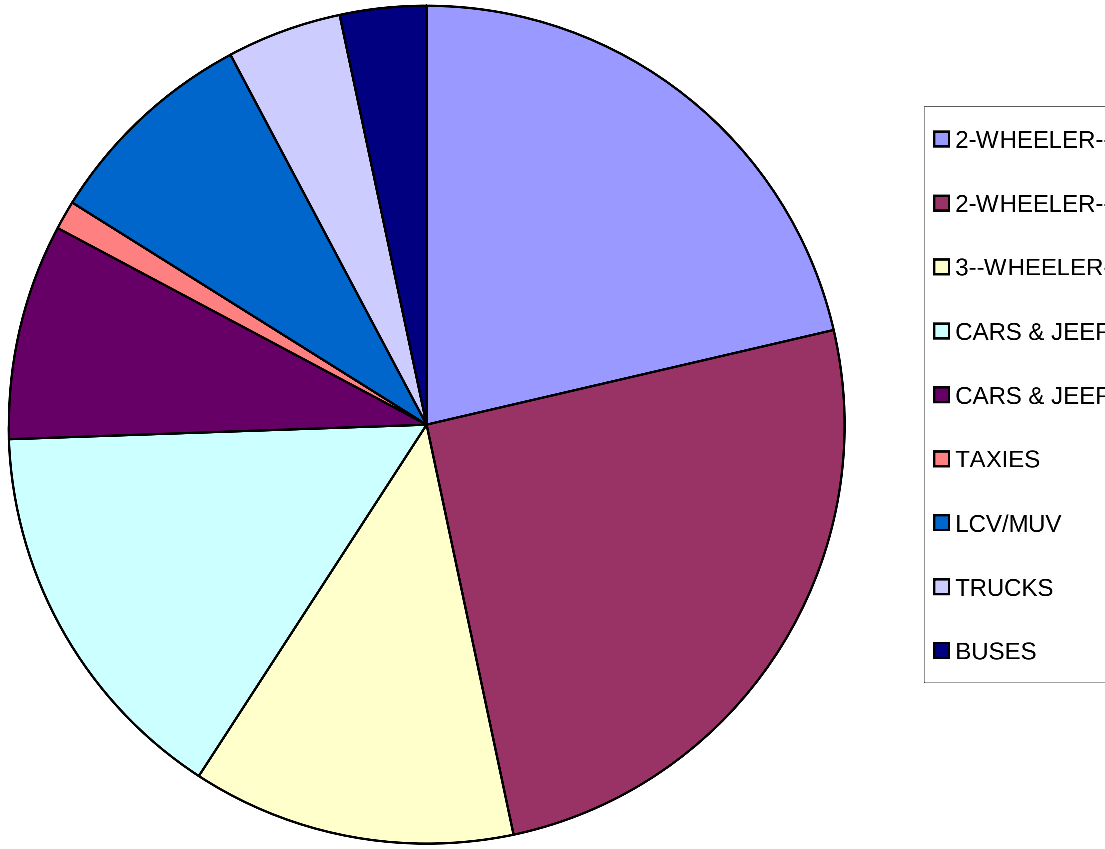


Figure 5.14 The HC Emissions From Various category of Vehicles During 2001-2006 (Total HC Emissions 87.7088 TPD)

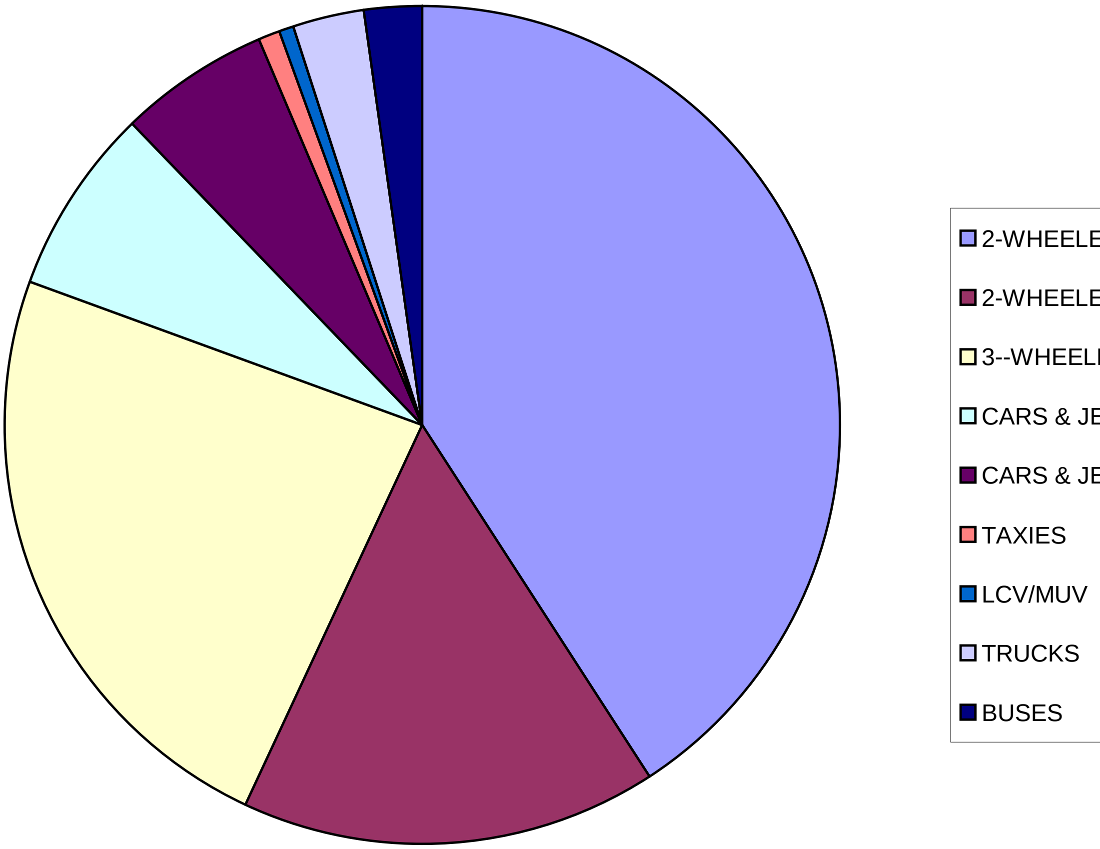


Figure 5.15 The NOx Emissions From Various category of Vehicles During 2001-2006 (Total NOx Emissions 74.932 TPD)

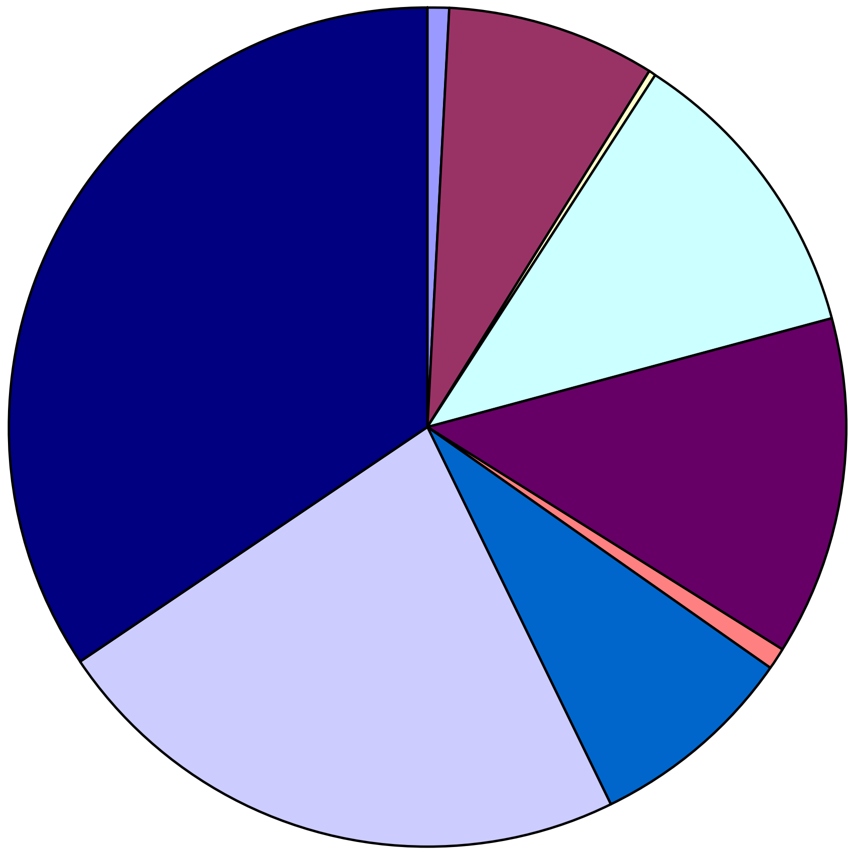
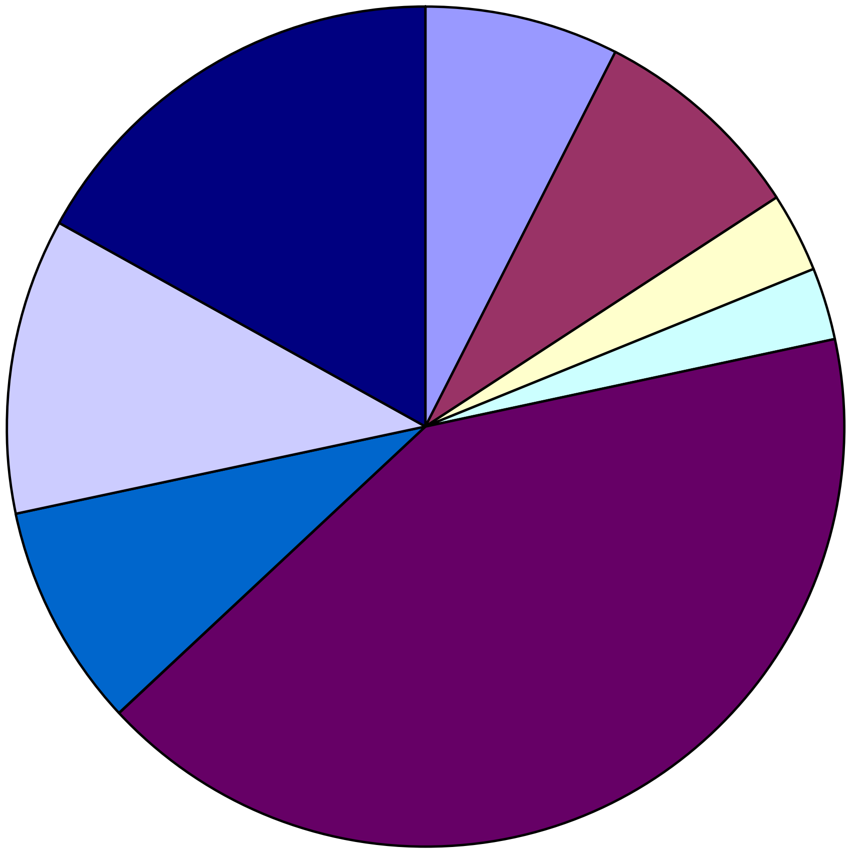


Figure 5.16 The PM Emissions From Various category of Vehicles During 2001-2006 (Total PM Emissions 14.35388 TPD)



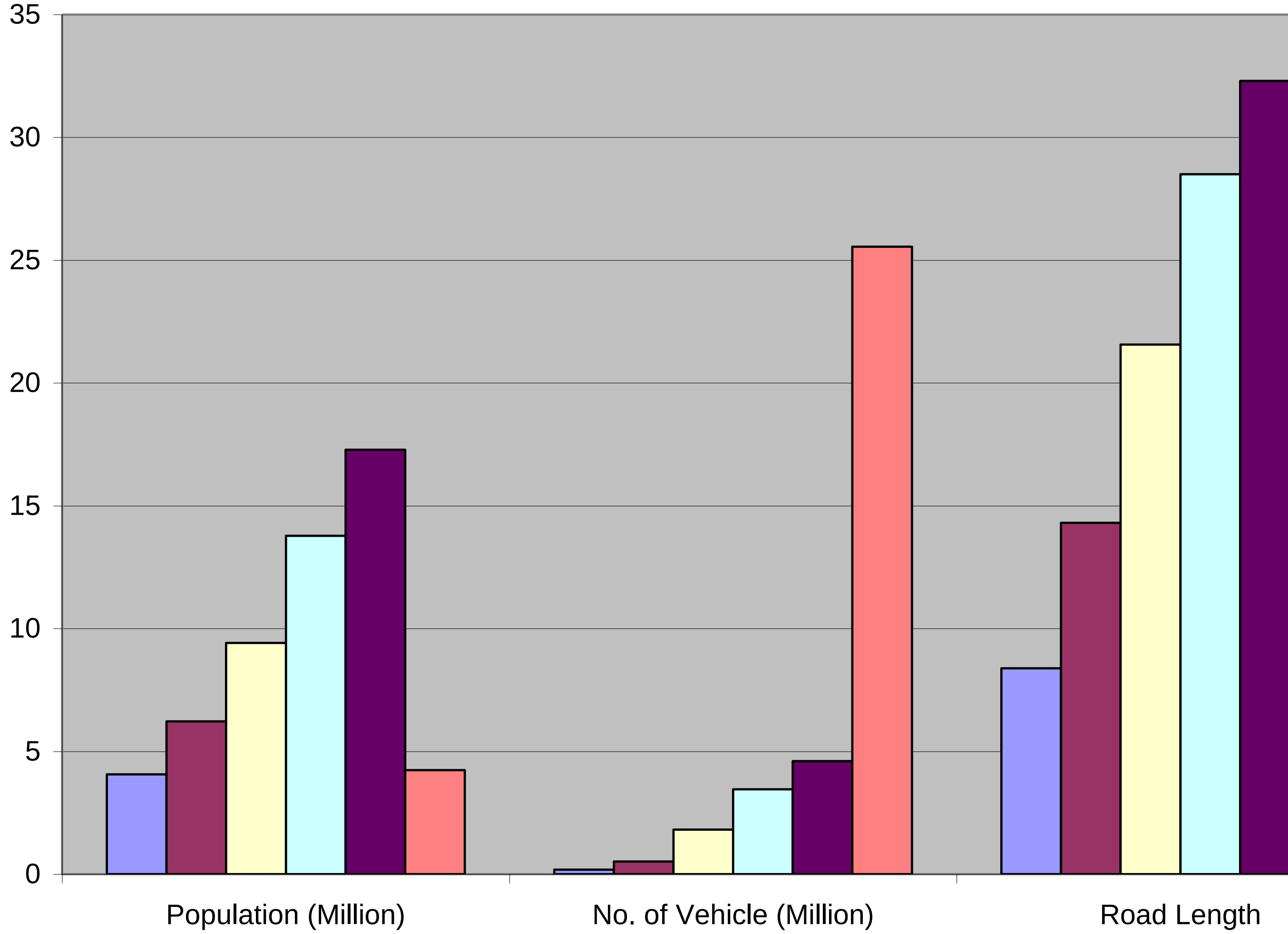


Figure 5.17 GROWTH OF VEHICULAR POPULATION IN DELHI (BASE YR 1971)

CONTROL STRATEGIES

Containment of vehicular pollution requires an integrated approach, the essential components of which include the following:

i. Improvement of public transport system (e.g. urban buses)

ii. Optimisation of traffic flow and improvement in traffic management (e.g. area traffic control system, no-traffic zone, green corridors, removal of encroachment on roads, regulation of construction activities and digging of roads).

iii. Comprehensive inspection and certification system for on-road vehicles.

iv. Phasing out of grossly polluting vehicles.

v. Fuel quality improvement (e.g. benzene and aromatics in petrol, reformulated gasoline with oxygenates/additives, reduction of sulphur in diesel).

vi. Tightening of emission norms (e.g. EURO-III by 2008)

vii. Improvement in vehicle technology (e.g. restriction on the 2 stroke engines, emission warranty, on-board diagnostic system).

viii. Checking adulteration of fuel.

ix. Checking evaporative emissions from storage tanks and fuel distribution system

x. Increasing the use of Alternative Fuels

xi. Promoting Electric Hybrid Vehicles

6.1 Improvement of public transport system

According to an estimate made by RITES, a modal split of 70-75% in favour of public transport needs to be planned for the city of Delhi. Presently, the modal share of public transport (Bus) is 62 percent. Along with the increase in number of buses, the passenger capacity should also be increased with the induction of high speed buses. The Metro Rail start serving the people with their entire satisfaction but its growth requires huge investment. Another is the mono rail and development of road infrastructure in Delhi The existing circular ring railway network also requires to be improved. These measures will not only meet the immediate requirements but also serve to the people of Delhi for long time.

6.1.1 High Capacity Buses

With rapid urbanisation, the pressure on transportation systems has increased in most cities in India. The inadequate transport system of cities, accompanied by lack of comprehensive urban transport management strategies is promoting the use of private individual transport. As an example, Delhi alone has experienced a nine fold increase in its motor vehicle population over the last three decades, with public transport contributing little to this increase. Significant environmental, safety and health implications are associated with high traffic density and inefficiently designed urban transport systems. Most cities continue to face the problems of environment pollution, slower vehicular speeds, and traffic congestion accompanied by unacceptable accident rates. As a result, urban India encounters acute transport crisis and deteriorating air environment. This situation calls for innovative, cost effective, safe and reliable transport strategies. Modern High Capacity Bus Systems (HCBS) integrated with information and communication technologies provide such an option for decongesting and improving urban transport situations. In most cities, buses are still the most widely used mode of conveyance and will continue to remain so. Therefore, it is crucial that urban planners start looking at innovative ways by which the efficiency of the bus transport can be improved to cater o the growing urban population. Preferential right of way for buses along with priority for pedestrians and cyclists, intelligent transport systems, cleaner fuels and vehicle technologies could be the way forward for meeting the transport needs of our cities in the future. HCBS is a term used for bus transportation systems that use available space on arterial roads of cities with dedicated bus ways. These systems utilize modern

technologies for optimising flow, passenger movement, ticketing, bus scheduling, etc. The efficiency of the system and high capacity of passengers transported depends on the system as whole and not necessarily on the size of buses, though when necessary articulated buses could be used with ease. HCBS is a high-quality customer oriented transit that delivers efficient, low cost and fast urban mobility. These systems can be implemented at a fraction of the cost of rapid transit systems available earlier. Such systems have the following characteristics: segregated bus ways, rapid boarding and alighting, efficient fare collection, comfortable and efficient shelters and stations, use of clean bus technologies not limited to any particular type, and flexibility in routing. Such systems increase the capacity of existing bus systems significantly and can be implemented in relatively short time spans of 1 -2 years.

Background on HCBS

HCBS systems have been introduced in a large number of cities in the developing world, and even advanced economies are now following this example. Basically, HCBS can be defined as a fully integrated, bus-based "rapid" transit system typically utilizing highly flexible service and advanced technologies to improve customer convenience and reduce delays. It combines most of the qualities of light rail transit with the flexibility and lower operating, maintenance, and capital cost of buses. HCBS vehicles can operate on exclusive travel ways, high occupancy vehicle (HOV) lanes, expressways, or ordinary roadways in almost any dense urban environment. In addition, HCBS can combine intelligent transportation systems (ITS) technology; traffic signal priority; rapid, limited stop service; clean, quiet, and aesthetically pleasing vehicles; enhanced shelters and stops; rapid and convenient fare collection; and facilitated integration with existing and future land-use policy. The following features typically characterize a HCBS system:

- Exclusive travel ways
- Modern stations
- Modern buses
- Rapid service
- Automated fare collection
- ITS technologies

- Lower costs

It is not necessary that all of the above systems be available at the same time. They can be incorporated in phases or as per need on different sections.

Exclusive travel ways

A “travel way” is the path along which a HCBS vehicle operates; the use of an exclusive travel way is what distinguishes HCBS from standard local trans it service and helps give it a higher-than-standard -bus speed, reliability, and identity. Some of the types of travel ways that can be used include exclusive transit way, HOV lanes, dedicated transit lanes, mixed traffic, contra flow lanes, and queue jumper lanes at signalized intersections. In some HCBS applications, the travel way is color-coded or has special pavement markings to enhance its distinctiveness. These exclusive lanes can be on the left (curbside) lane or on in the centre of the right of way. Extensive experience has been accumulated around the world in the allocation of these locations and the decisions have to be based on land use patterns, right of way available and density of bus traffic. In some locations, emergency vehicles and high capacity vehicles like taxis are also allowed on these lanes.

Modern stations

HCBS system stations can range from standard shelters to large transit centers, depending on the character and/or the density of the community in which the HCBS operates. HCBS stations often are tied to major activity centers such as malls, business parks, and downtowns, and even can be located “off-line” from the travel way. Typically, station design further promotes fast, efficient HCBS service by reducing vehicle dwell time. One of the major ways that this is accomplished is by speeding up the passenger boarding and alighting process by using raised platforms for no-step passenger movement on and off the vehicles and/or buy the use of low floor buses. HCBS stations also utilize signage and graphics to differentiate and make them stand out from standard bus stops. In addition, HCBS stations also can include real-time passenger information displays and provide opportunities for other customer services.

Modern buses

In the early stages it may not be absolutely necessary to provide all buses that are new, but the full capacity of the system can be achieved only if the bus designs I integrated with the bus stop and communication systems. Some of the critical issues are outlined below.

Low-Floor Vehicles

HCBS systems typically use low floor buses to reduce dwell time, make travel more convenient and make possible use by disabled persons easier. For disabled persons, access to the vehicle can either be at raised platforms (providing *level boarding*) or using an on-vehicle ramp which flips down to bridge the gap between the step and the curb.

Number and Width of Doors

HCBS require buses with more and wider doors to reduce dwell time. A clear width of 820 mm is desirable for easy access by persons in mobility aids. Three doors may be there in a 12m bus, which increase passenger-handling capability at stops or stations by 50 percent.

Internal Circulation

HCBS systems should make movement of passengers within the bus smoother and faster. Wider aisles and higher standing capacity can increase overall capacity of the bus and also improve movement inside the bus. However, these designs require careful ergonomic design of seats, aisles and grab-handles and poles.

Noise and Emissions

The success of the HCBS system also depends on its public image and environmental issues. Therefore, the HCBS buses must be less polluting and quieter in operation.

Safety

Special care needs to be given to make these buses safer both for occupants and for other road users around them. In future these items could include IT systems for hazard detection and roadway information systems.

Propulsion

All modes of propulsion – diesel, CNG, LPG, hydrogen cell, electric trolley buses (ETB) – can be used in HCBS. ETBs are proven technology, have no emissions from the tailpipe, and are the quietest transit mode of all, but they are costlier than other buses.

Rapid service

HCBS provides a wide array of options for integrating the various systems. High-speed express buses can operate on the same route as regular buses. To enable this, overtaking facilities have to provide only at those stops which are to be skipped at the express buses. Buses entering the HCBS route from other routes can also provide faster travel on this section.

Automated fare collection

In most bus systems, fare collection slows down operations. The new system should incorporate use of smart cards, ticketing at bus stops, wider use of weekly/monthly passes, etc.

ITS technologies

Providing information to customers is a crucial part of providing reliable, efficient, and convenient service. A customer arriving at a stop or station should be able to readily find information about routes, the hours and frequency of service, a system map, and other pertinent information. Although this type of static information is useful, real-time information is even more valuable to customers. Such information requires the use of ITS technologies such as an automatic vehicle location (AVL) system to track the exact location of vehicles in the system. The information from the AVL system then can be converted into vehicle arrival times that can, in turn, be displayed in real time to customers at stations, kiosks, Internet/radio/television, or transmitted over information networks. Customer information inside the bus can also provide real time data regarding present location, next stops and estimated time to destinations. Another important component of HCBS is *Traffic Signal Priority,* which is simply the idea of giving special treatment to transit vehicles at signalized intersections. Since transit vehicles can hold many people, giving priority to transit can potentially increase the person throughput of an intersection. There are many different options for signal priority logic. Real-time, *adaptive* systems can incorporate information on traffic flow, flow coordination, bus schedule adherence, and prior bus arrival times. These systems are now relatively inexpensive and can be incorporated both in the bus and traffic signals.

Issues for Delhi

Various types of bus operations are possible including local services with frequent stops, express service with limited stops, peak period services, charter services, feeder services and shuttle services. The standard of service is usually perceived in terms of reliability, frequency, journey time, and quality of ride, which may vary from air-conditioned comfort to extreme crush loading conditions. Other than the low cost compared to rail based transit options, a major advantage of bus transit is its flexibility in meeting changes in the shape of the city development and in changes in demand in terms of quantity and quality. If necessary, existing bus routes can be modified almost overnight at virtually no cost. Expanded or new services can be introduced quickly and at relatively low initial cost. Electric trolleybus systems, however, lack the flexibility of conventional bus transit because they are constrained by their overhead power transmission system, and involve considerably higher costs, although substantially lower than rail based system. The trolleybuses can be considered as low-cost non-polluting solution for high volume polluted corridors. Use of ETBs does not preclude other buses form using the same corridor as the road surface is not altered.

The "critical" element in city transport systems

Meeting the specific needs of the most vulnerable groups in the city becomes crucial for the efficient performance of all traffic. For low-income people commuting to work, walking, bicycling or affordable public transport are not a matter of choice but a necessity for survival. Therefore, whether the roads have any specific facilities for these modes or not, they continue to be used by them. Delhi traffic laws do not segregate bicycle traffic and enforcement of speed limits is minimal. Motor vehicles (MVs) and non-motorized vehicle (NMVs) have different densities at peak traffic hours at different locations in the city. The existing traffic characteristics, modal mix, location details, geometric design, land use characteristics, and other operating characteristics present a unique situation where economic and travel demand compulsions have overwhelmed the official plans. On the two and three lane roads, bicycles primarily use the outermost lane on the left, i.e. curb side lane, and MVs do not use the left most lanes even at low bicycle densities. Bicyclists use the middle lanes only when they have to turn right. A study of fourteen locations in Delhi shows that maximum mixing of NMVs and MVs occurs at the bus stops. Their interaction with other MVs is minimal at other locations. On three lane roads, the MV flow rates are close to or less than 4000 passenger car units per hour. This is much less than the expected capacity of three lane roads. The flow for these urban localities can be taken as 2000 passenger car units per hour per lane (Indian Road Congress). Though the peak volumes are not exceeding saturation capacities, we find the average speed remains in the range of 14–39 km/h. This shows that the left most lane is only partially used. However, if a space was exclusively available for bicyclists, through out would increase by reducing friction with buses. Though de facto segregation takes place on three lane roads, an unacceptable danger exists to bicyclists because of impact with MVs. At three-lane locations, it is a waste of resources not to provide a separate bicycle lane because bicycles, irrespective of bicycle density, occupy one whole MV lane. Since bicycles and other non-motorized vehicles use the left side of the road, buses are unable to use the designated bus lanes and are forced to stop in the middle lane at bus stops. This disrupts the smooth flow of traffic in all lanes and makes bicycling more hazardous. Motorized traffic does not use the curbside lane even when bicycle densities are low. Providing a separate bicycle track would make more space available for

Table 6.1 Criteria for site specific choice between a central bus-lane layout and a curb -side bus -lane layout

Sl. No.	Central Bus Lane	Curb-Side Bus Lane
1.	**Excessive side-entries for vehicles into service lanes or individual plots.**	**Limited access to service lanes or widely spaced entry points into adjoining area.**
Rationale	The high volume of turning traffic interferes with the through movement of bus traffic if the bus uses the same curb-side lane as the turning vehicles.	
2.	**Closely placed traffic lights for vehicles.**	**Traffic lights at larger intervals.**
Rationale	Buses using the curb-side lane are forced to stop at every red signal with other vehicles reducing throughput and encouraging passengers to board and alight in unsafe areas.	
3.	**Low frequency of bus-stops**	**Higher Frequency of bus -stops**
Rationale	If the frequency of bus -stops is higher a central bus-lane will create too many pedestrian crossings defeating the its purpose while a curb-side bus lane will provide safer and more efficient bus -stops.	
4.	**Higher volume of two-wheeler and three-wheeler vehicles**	**Lower volume of two-wheeler and three-wheeler vehicles**
Rationale	High volumes of two-wheeler and three -wheeler vehicles interfere with the movement of buses in the curb -side lane especially at the bus-stops where buses often cannot approach the designated bus-bays due to the three -wheelers parked there and the two-wheelers trying to overtake from the left-side. Also, the difference in sizes of these vehicles sharing the curb -side lane makes the situation unsafe for the smaller vehicles.	
Eg.	**Arterials through heavy commercial landuse areas like Vikas Marg**	**Highways through large institutional areas like stretch of Ring Road in ITO area.**

motorized modes and bicycling less hazardous. Therefore, the critical element on Delhi roads that influences the efficiency of all motorised modes is the presence of non-motorised traffic. A pre-condition for providing an efficient HCBS would be the provision of physically segregated lane for non-motorised traffic. HCBS corridor designs would have to give due consideration to this issue.

Table 6.2: Capacity Estimation in different scenario

Current				Exclusive Cycle track provided			Cycle track and HCBS		
Vehicles/h		Pers/h			Pers/h	Pers/h		Pers/h	Persons/h
		Bus=40	bus=80	Veh./h	bus=40	Bus=80	Veh./h	bus=40	bus=80
Cars	1404	1614.6	1614.6	1404	1614.6	1614.6	1404	1614.6	1614.6
MTW	1652	3634.4	3634.4	1652	3634.4	3634.4	1652	3634.4	3634.4
BUS	248	9920	19840	324	12960	25920	486	19440	38880
TSR	454	799.04	799.04	454	799.04	799.04	454	799.04	799.04
Cycle	338	354.9	354.9	338	354.9	354.9	4500	4725	4725
Total	4096	16322.94	26242.94	4172	19362.94	32322.94	8496	30213.04	49653.04
	~	**16000**	**26000**		**19000**	**32000**		**30000**	**49000**

Increased capacity

If a separate segregated lane is constructed for HCBS and bicycles, the curbside lane, which is currently used by bicyclists, becomes available to motorized traffic and buses. This relatively small investment in bicycle lanes can increase the road space for motorized traffic by 50% on three lane roads. Bicycle lanes also result in better space utilization. For instance a 3.5 m wide lane has a carrying capacity of 1800 cars per hour whereas it can carry 5400 bicycles per hour. Given the fact that there is not much space available to expand existing roads, the future mobility needs and projected trips can only be met by increasing the capacity of the existing road network. This can only be achieved by encouraging modes that are more efficient in terms of space utilization. Motorized vehicles benefit because of improved capacity of the road and improvement in speeds. Capacity estimations of a typical arterial road in Delhi show improvement in corridor capacity by 56–73% by provision of a high capacity bus lane and NMT lane. A dedicated lane is provided for bicycles and the curbside lane is exclusively reserved for buses operating as HCBS. Other two lanes are used by all other motorized traffic. A dedicated 3 m wide bicycle lane can carry 4500 bicycles (maximum capacity of an urban lane is 1800 PCU ~ 4500 bicycles). Exclusive bicycle lane releases space on left most lane for buses. Therefore the maximum capacity of the left most lane is 1800 PCU ~ 486 buses (Table6.2). The results of the capacity estimation show that with the corridor capacity measured in terms of persons/ hour in existing patterns of mixed traffic, capacity can be improved by 19% by providing exclusive bicycle tracks. If the bus occupancy is taken as 80 persons/bus then 23% improvement in capacity can be realised by providing exclusive bicycle tracks. Not only does extra space on the main carriageway become available to other modes, the dedicated bicycle track also provides a higher capacity for bicyclists. Provision of exclusive bicycle track also provides an opportunity to develop left lane as an exclusive bus lane. Table 6.2 shows 88% improvement in capacity from 16000 (40 persons/bus) and 26000 (80 persons/bus) to 30000 persons and 49000 persons respectively. This is achieved by running 486 buses in the exclusive bus lane and 4500 cycles in the exclusive cycle lane. Table 6.3 shows capacity of the main carriageway (three lanes used by motorized vehicles). This does not include capacity provided by the cycle track. Corridor capacity improves by 19-23% by providing exclusive cycle track. However, utilizing the full capacity of the corridor i.e. provision of high capacity bus system in the left most lane can lead to capacity improvement by 56-73%.

Table 6.3: Capacity in persons/h in three MV lanes (excluding bicycles)

	Bus=40		Bus=80	
	ExclusiveCycle Track	Exclusive cycle track and HCBS	ExclusiveCycle Track	Exclusive cycle track and HCBS
Car	1614.6	1614.6	1614.6	1614.6
MTW	3634.4	3634.4	3634.4	3634.4
Bus	12960	25920	19440	38880
TSR	799.04	799.04	799.04	799.04
TOTAL ~	**19000**	**32000**	**25000**	**45000**

Improved speeds

Improvement in speeds of motorized vehicles will be experienced until the corridor is full to capacity due to realization of induced demand. Major beneficiaries of speed improvement are buses and two wheelers because curbside lanes become available to them without interference from slow vehicles. Estimations of time savings experienced by bus commuters, car occupants and two wheeler commuters on a typical arterial corridor in Delhi show 48% reduction in time costs due to 50% improvement in bus speeds (from present 15 km/h to 30 km/h) and 30% improvement in car and two wheelers.

Reduced congestion

Congestion has long been recognized as an environmental problem. Other than causing delay, it causes noise and fumes and increases health risks to road users and residents. Delhi as well as other Indian cities have invested in grade separated junctions and flyovers as one of the major congestion relief measure at an average cost of Rs. 100 million to 300 million for each intersection. However, detailed simulation of a major intersection in Delhi shows that re-planning the junction to include separate NMV lanes and bus priority lane can bring in 80% improvement over the present level of delays. Cost of this measure is 25 times less than the proposed grade-separated junction.

Increased safety

By creating segregated bicycle lanes and re-designing intersections, conflicts between motorized traffic and bicyclists can be reduced substantially leading to a sharp decrease in the number of accidents and fatalities for bicyclists and motorized two-wheelers. Safety benefits estimated for a typical arterial in Delhi show 46% reduction in accident costs. This is because a segregated facility reduces injury accidents by 40% and fatalities by 50%.

International Evaluations

1. A recent World Bank study makes the following comments on HCBS systems:

- HCBS is clearly beneficial to the poor. Many of the poor use buses and bus ways create major accessibility benefits for them, particularly when they live in the outer city areas, and particularly with ‘open’ systems, or ‘trunkand- feeder’ when there is through-ticketing. If ‘greener’ bus ways were developed, then the poor in particular would benefit from this through better health (they often spend long hours living, working or traveling in the street environment), but maybe at the expense of higher tariffs.

- Bus ways – where they are politically acceptable, bus ways should often be the first step in MRT system development, and for many cities they will remain the MRT system for the foreseeable future. We have seen that they can – in the right environment, effect major improvements in accessibility, benefiting most of the city's population, and particularly the poor. And they can achieve this quickly and incrementally as conditions and funding allow.

- There are two forms of bus way, ' open' in which buses join and leave, providing convenience for passengers who do not need to change bus; and ' trunk-and-feeder' which operates like light rail and requires interchange, often involving ' through-ticketing' and requiring more sophisticated institutional arrangements. The advantage is the additional operational control and capacity, which is created. Bus way output depends greatly on road network configuration, junction spacing and stop spacing.

- An evaluation from the United States General Accounting Office on bus rapid transit sates that HCBS is generally more flexible than light rail: Bus Rapid Transit can respond to changes in employment, land-use, and community patterns by increasing or decreasing capacity. Bus Rapid Transit routes can also be adjusted and rerouted over time to serve new developments and dispersed employment centers that may have resulted from urban sprawl. On the other hand, Light Rail lines are fixed and cannot easily change to adjust to new patterns of housing and employment. Although Bus Rapid Transit sometimes uses rail-style park-and-ride lots, Bus Rapid Transit routes can also collect riders in neighborhoods and then provide rapid long-distance service by entering a bus way or HOV facility.

TABLE 6.4: Public Transport Options

Characteristic	BUSWAY	LRT	METRO	SUBURBAN RAIL
Current Applications	Widespread in Latin America for 20+ years	Widespread in Europe Few in dev' g cities, none with 'high' ridership	Widespread, skewed to Europe and North America	Widespread, skewed to Europe and North America
Segregation	At-grade	At-grade	Mostly elevated/u' gd	At-grade
Space req' d	2-4 lanes from existing road	2-3 lanes from existing road	Elevated or u' gd, little impact on existing road	-
Flexibility	Flexible in both imp' n and op' s, robust operationally	Limited flexibility, risky in financial terms	Inflexible and risky in financial terms	Inflexible
Impact on Traffic	Depends on policy/design	Depends on policy/design	Reduces congestion somewhat	May increase congestion when frequencies high
PT Integration	Straightforward with bus operations. Problematic with paratransit	Often difficult	Often difficult	Usually existing
Initial Cost US$mn/km	1-5	10-30	15-30 at-grade 30-75 elevated 60-180 u' gd	-
Practical Capacity Pass/hr/direction	10-20,000	10-12,000? (no examples)	60,000+	30,000
Operating Speed Kph	17-20	20? (no examples)	30-40	40-50+

- Transit agencies have considerable flexibility to provide long distance service without requiring a transfer between vehicles. This is a significant benefit, because some research has shown that transit riders view transferring to be a significant disincentive to using mass transit. In contrast, Light Rail systems frequently require a transfer of some type— either from a bus or a private automobile. When Light Rail lines are introduced, transit agencies commonly reroute their bus systems to feed the rail line. This can have the effect of making overall bus operations less efficient when the highest-rider ship bus route has been replaced by Light Rail; the short feeder bus routes can be relatively costly. Finally, bus-based systems' ability to operate both on and off a bus way or bus lane provides Bus Rapid Transit the flexibility to respond to operating problems. For example, buses can pass disabled vehicles, while Light Rail trains can be delayed behind a stalled train or other vehicle on the tracks. Thus, the impact of a breakdown of a Bus Rapid Transit vehicle is limited, while a disabled Light Rail train may disrupt portions of the system. o Bus Rapid Transit systems differ from Light Rail systems in that they provide greater flexibility in how they can be implemented and operated. In constructing a Bus Rapid Transit system, it is not necessary to include all the final elements before beginning operations; it is possible to phase in improvements over time. Improvements such as signal prioritization and low floor buses, which improve capacity and bus speed, can be added incrementally. These incremental changes can have significant effects. 3. Robert Cervero, a professor of city and regional planning al the University of California at Berkeley whose recent research focuses on suburban transit issues says that "Certainly, buses are the most significant piece of the pie when it comes to transit. Far more people ride buses than rail. Plus our settlement patterns are more compatible with a more flexible transit mode. Too many American cities have it backwards. Instead of starting with compact development, they operate under the false assumption that, if you build rail lines, you will get people out of their cars." In Cervero's view, that won't happen until local officials make land-use decisions that support transit. His models are mostly foreign the German city of Essen, for instance, and Adelaide, Australia, both of which have guided bus ways. He points to Edmonton, Alberta, for its convenient transfer centers where "pulse scheduling" of local buses eliminates much of the waiting lime. U.S. examples include the Seattle suburb of Bellevue (where buses tie into a pedestrian path system); Portland, Oregon; Orange County, California: and the Norfolk area. Cervero makes the point that systems should be tailored to meet particular needs. That could mean flexible s rather than fixed service.

6.1.2 Metro Rail in Delhi

Delhi, the capital city of India, is one of the fastest growing cities in the world with a population of 13 million as reported in the Census of India Report for the year 2000. Until recently, it was perhaps the only city of its size in the world depending almost entirely on roads as the sole mode of mass transport. The total length of the road network in Delhi has increased from a mere 652 km in 1981 to 1122 km in 2001 and it is expected to grow to 1340 km in the year 2021. This increase in road length is not at par with the phenomenal growth in the number of vehicles on these roads in Delhi. The cumulative figure of registered private and government buses, the main means of public transport, is

41,872 in 1990 and it is expected to increase to 81,603 by the year 2011. The number of personal motor vehicles has increased from 5.4 lakhs in 1981 to 30 lakhs in 1998 and is projected to go up to 35 lakhs by 2011. With gradual horizontal expansion of the city, the average trip length of buses has gone up to 13 km and the increased congestion on roads has made the corresponding journey time of about one hour. Delhi has now become the fourth most polluted city in the world, with automobiles contributing more than two thirds of the total atmospheric pollution. In this context, the decision of the Government of India to develop a mass transport system for Delhi providing alternative modes of transport to the passengers was most appropriate.

The first concrete step in the launching of an Integrated Multi Mode Mass Rapid Transport System (MRTS) for Delhi was taken when a feasibility study for developing a multi-modal MRTS system was commissioned by the Government of the National Capital Territory of Delhi (GNCTD) at the instance of the Government of India in 1989 and completed by Rail India Technical and Economic Services Limited in 1995 (RITES, 1995a, 1995b). The Delhi Metro (DM) planned in four phases is part of the MRTS. The work of Phase I and part of Phase II is now complete while that of phase III is in progress. The first phase of DM consists of 3 corridors divided in to eight sections with a total route of 65.1 kms, of which 13.17 kms has been planned as an underground corridor, 47.43 kms as elevated corridors and 4.5 kms as a grade rail corridor. The second phase covers 53.02 kilometers of which the underground portion, grade and elevated section are expected to be 8.93 kilometers, 1.85 kilometers and 42.24 kilometers respectively. The construction of the first phase of DM was spread

over 10 years during 1995-96 to 2004-05 while that of the second phase, which started in 2005-2006 is expected to be complete by 2010-11. The total capital cost of DM at 2004 prices for Phase I and Phase II are estimated as Rs. 64,060 and Rs. 80,260 million, respectively. Phases III and IV of DM will cover most of the remaining parts of Delhi and even extend its services to some areas such as Noida and Gurgaon belonging to the neighboring states of Delhi. Table 6.5 provides some of these details.

Table 6.5: Overview of the MRTS

	Phase I (1995 - 2005)	Phase II (2005 –2011)
Distance	65.10 km	53.02 km
Corridors	1) Shahdara - Barwala (22)	1) Vishwa Vidhyalaya- Jahangirpuri (6.36)
	2) Vishwa Vidhyalaya- Central Secretariat (11)	2) Central Secretariat- Qutab Minar (10.87)
	3) Barakhamba Road - Dwarka (22.8)	3) Shahdra- Dilshad Garden (3.09)
	4) Barakhamba Road – Indraprastha (2.8)	4) Indraprastha- New Ashok Nagar (8.07)
	5) Extension into Dwarka Sub city (6.5)	5) Yamuna Bank- Anand Vihar ISBT (6.16)
		6) Kirti Nagar- Mundka (18.47)
Investment	Rs 6406 crores (2004 prices)	Rs 8026 crores (2004 prices)
	Phase III	**Phase IV**
Distance	62.2 km	
	1) Rangpuri to Shahabad Mohammadpur	1) Jahangirpuri to Sagarpur West
	2) Barwala to Bawana	2) Narela to Najafgarh
	3) Jahangirpuri to Okhla Industrial Area Phase I	3) Andheria Mod to Gurgaon
Corridors	4) Shahbad Mohammadpur to Najafgarh	

Financial Costs and Benefits of the Metro

It is important to examine the financial feasibility of DM before actually taking up its economic appraisal. The financial evaluation of a project requires the analysis of its annual cash flows of revenue and costs considering it as a commercial organization operating with the objective of maximizing private profits. The financial capital cost of DM represents the time stream of investment made by it during its lifetime. The investment expenditures made by the project in one of the years during its life time constitutes the purchase of capital goods, cost of acquisition of land and payments made to skilled and unskilled labour and material inputs for project construction. The operation and maintenance cost of the project constitutes the annual expenditure incurred on energy, material inputs for maintenance and payments made to skilled and unskilled labour. The investment goods and material inputs used by the project are evaluated at market prices, given the definition of market price of a commodity as producer price plus commodity tax minus commodity subsidy. If the government gives some commodity tax concessions to DM, they are reflected in the prices paid by

DM for such commodities. If the financial capital cost of the project is worked out as the time flow of annualized capital cost, the annual cost of capital has to be calculated at the actual interest paid by it. This could be done using information about the sources of funds for investment by DM and the actual interest paid by it to each source. For example, if part of the investment of DM is financed out of loans provided by the government at the subsidized interest rate, the annual cost of this investment has to be calculated at the subsidized interest rate.

Table 6.6 provides the sources of funding investments of DM (phases I and II). More than 60 percent of the funds required for investment are raised as debt capital. Around 30 percent of total investments of DM are raised through equity capital with the Government of India (GOI) and GNCTD having equal shares in it. The remaining 10 percent of the investments of DM will be covered out of the revenues it earns. As reported in RITES (1995a), the DM had been provided with the following concessions by GOI to make the project viable, namely (a) The cost of land equivalent to Rs. 2180 million has been provided as an interest free subordinate loan by GOI/GNCTD to be repaid by the DM within 5 years after the senior debt is repaid fully by the twentieth

year of taking the loan (b) The risk associated with the exchange rate fluctuations is borne by government in case of foreign debt, (c) The DM is exempted from payment of income tax, capital gains tax, property tax and customs duty on imports, (d) The DM is permitted to generate resources through property development over a period of 6-20 years and (e) No dividend is paid on GOI share of equity till the senior debt is repaid fully by the twentieth year.

Table 6.6: Sources of Funding

Cost Financed By	Phase I	Phase II
1) Equity (50% each by GOI & GNCTD)	30%	30%
2) Long Term Debt (OECF, Japan) @ 3% p.a. or less	60%	56%
(with a 10 year moratorium period and 10 year repayment period)		
3) Revenues From Property Development	7%	5%+ 5% (internal resources)
4) Subordinate Debt	3%	4%

Table 6.7: Cost Estimate D M (Phase I)

(Rs. Million)

Items	Foreign Exchange	Local Cost	Total
Civil works	0	31327	31327
Electrical works	0	6970	6970
Signaling and telecommunication	2574	1930	4504
Rolling stock	4596	6403	10999
Land	0	3339	3339
General establishment and consultancy charges	322	4779	5101
Contingencies	230	1593	1823

Table 6.8: Estimates of Financial Flows of Investment by D M (Phases I and II) During its Life Time

(Rs. Million)

Year	Capital Cost	Year	Capital Cost	Year	Capital Cost	Year	Capital Cost
1995	2574	2007	20411	2019	361	2031	43290
1996	3937	2008	23331	2020	1543	2032	15150
1997	6036	2009	17861	2021	18901	2033	0
1998	8625	2010	5281	2022	1183	2034	0
1999	9498	2011	1271	2023	1183	2035	0
2000	10110	2012	361	2024	1183	2036	0
2001	9069	2013	361	2025	0	2037	0
2002	7353	2014	361	2026	0	2038	0
2003	4917	2015	361	2027	0	2039	0
2004	1945	2016	361	2028	0	2040	0
2005	4061	2017	361	2029	0	2041	58770
2006	12381	2018	361	2030	0		

Table 6.7 provides information about various components of capital cost for Phase I of DM. The total project cost of Rs. 64,060 million at 2004 prices for Phase I consists of the foreign exchange cost of Rs. 7720 million and the domestic material and labour cost of Rs. 56,340 million. The corresponding figure for the Phase II of DM is Rs. 80,260 million at 2004 prices.

Table 6.9: Estimates of Financial Flows of Operation and Maintenance (O&M) Expenditures by DM (Phases I and II) During its Life Time

(Rs. Million)

Year	O&M	Year	O&M	Year	O&M
2005	3123	2017	10484	2029	20149
2006	3253	2018	10981	2030	21255
2007	3387	2019	11507	2031	24628
2008	3527	2020	12127	2032	26042
2009	3674	2021	13763	2033	27562
2010	7822	2022	14374	2034	29198
2011	8006	2023	15032	2035	30958
2012	8366	2024	15738	2036	32852
2013	8745	2025	16498	2037	34891
2014	9145	2026	17316	2038	37086
2015	9568	2027	18195	2039	39449
2016	10013	2028	19141	2040	41993

Table 6.9 provides the estimated financial flows of capital cost of DM at 2004 prices during its lifetime. RITES (1995a, 2005b) provide the estimates of operation and maintenance cost (O&M cost) of DM. These estimates are made using information about the trends of the O&M cost of Calcutta Metro and the suburban sections of the Bombay Railway and the results of some optimization studies conducted. Table 6.9 provides the estimates of O & M cost of DM at 2004 prices during the lifetime of the project.

The financial benefits from the Metro are the fare box revenues and the revenues from advertisement and property development, as reported by RITES. Revenue streams for Phases I and II, as reported by RITES (1995b, 2005b) have been taken. The main source of revenue of the MRTS system is the fare box collection, which is a product of the total passenger rider ship on the MRTS as reported in Tables 6.10 and 6.11 and the fare charged. RITES (1995b) considered four rates per trip: Rs 3, 4, 5, 6 at April 1995 prices and the fare sensitivity of rider ship. Full rider ship is expected to materialize on the metro with a fare comparable to the DTC bus fare of Rs. 3 per passenger trip. However, with higher fares, the rider ship is expected to decline given that the willingness of passengers to travel by the metro depends on the value they place on time savings, frequency and safety of service, comfort and ease of travel, capacity to pay, etc.

Table 6.10: Fare Sensitivity of Rider ship on the Metro

Fare Rate (In Rs/Passenger trip)	Percentage Ridership
3	100%
4	90%
5	75%
6	50%

Table 6.11: Estimates of Daily Passenger Trips by Metro (in lakhs)

Year	Daily Passenger Trips
2002	12.63
2003	20.15
2004	23.86
2005	31.85
2006	33.17
2007	34.55
2008	35.97
2009	37.46
2010	39.01
2011	40.63
2012	41.81
2013	43.03
2014	44.29
2015	45.58
2016	46.91
2017	48.28
2018	49.69
2019	51.14
2020	52.63
2021	54.17

The financial model consisting of Rs. 5 per passenger trip and an annual fare increase of 7.5 per cent was considered optimal by RITES. The revenue collected by DM every year during its life time consists of revenue from the passenger traffic diverted from the road to the Metro and the revenue from serving part of the growing passenger traffic demand in Delhi. Table 6.12 presents the estimates of revenue collected by DM during its lifetime. Considering the estimates of financial flows of DM during the period 1995-2041, the financial cost-benefit ratio is estimated as 2.30 and 1.92 at 8 percent and 10 percent discount rates, respectively. The financial internal rate of return of DM is estimated as 17 percent.

Table 6.12: Estimates of Financial Flows of Revenue Earned by DM (Phases I and II) During its Lifetime

(Rs. Million)

Year	Revenue	Year	Revenue	Year	Revenue
2005	15052	2018	67722	2031	128687
2006	17152	2019	74284	2032	133307
2007	19407	2020	82806	2033	134177
2008	21826	2021	92342	2034	139477
2009	24421	2022	99126	2035	140477
2010	33762	2023	106242	2036	146547
2011	37112	2024	115557	2037	147687
2012	41057	2025	116067	2038	154657
2013	44511	2026	119127	2039	155947
2014	50847	2027	119717	2040	163947
2015	49633	2028	123227	2041	165437
2016	5627	2029	123897		
2017	62209	2030	127927		

Identification Of Economic Benefits And Costs Of Metro

Description of economic benefits and costs of the Delhi Metro requires the identification of the changes brought out by it in the transport sector of the economy. Most importantly, DM contributes to the diversion of a very high proportion of current passenger traffic from road to Metro and serves part of the growing passenger traffic demand in Delhi. As a result, there will be a reduction in the number of buses, passenger cars and other vehicles carrying passengers on Delhi roads with the introduction of the Metro. There will be savings in travel time for passengers still traveling on roads due to reduced congestion and obviously also for those traveling by Metro. The Metro also brings about a reduction in air pollution in Delhi because of the substitution of electricity for petrol and diesel and reduced congestion on the roads. There will also be a reduction in the number of accidents on the roads.

Investment in the Metro could result in the reduction of government investments on road developments and buses as also in the private sector investment on buses, passenger cars and other vehicles carrying passengers. There will be reductions in motor vehicles' operation and maintenance charges to both the government and the private sector. There could be cost savings to passenger car owners in terms of capital cost and operation and maintenance costs of cars if they switch over from road to Metro for travel in Delhi. The fare box revenue collections by Metro will be at the cost of the revenue, accruing earlier to private and the government bus operators and hence constitutes a loss in income.

The Delhi public will gain substantially with the introduction of the Metro service. It saves travel time due to a reduction of congestion on the roads and lower travel time of the Metro. There will be health and other environmental benefits to the public due to reduced pollution from the transport sector of Delhi. Land and house property owners gain from the increased valuation of house property prices due to the Metro. The Metro has the effect of increasing the income of the regional economy of Delhi vis a vis the rest of the Indian economy. Given that the per capita income of Delhi is far higher than the national per capita income, the redistribution of income in favour of Delhi may not be desirable from the point of view of income distribution in the Indian economy. The Metro provides employment benefits to the unskilled labour especially during its construction period. This labour is otherwise unemployed or under employed in the Indian economy.Various economic agents relevant for Metro could be identified as the government, passengers, transporters, general public and unskilled labour. Unskilled labour employed on the Metro gains to the extent of the difference between the project wage rate and the shadow wage rate. The social premium on investment and savings and foreign exchange accrue to the society represented by the General Public.

The flows of net economic benefits (NEB) of DM to the various economic agents could be computed as follows:

Government: $NBg = (Rm + Obpub + Ibpub + I_{ri} + R_{t)} – (Im + Om + Rbpub + R_t)$

Passengers: $NBp=((Rbpri+ Rbpub) - Rm) + Bst + (Ipv + Opv) + Bra$

Transporters: $NBt = Obpri - Rbpri$

Unskilled labour: $NBul = (1 – P_{DUL}) (Iml + Oml)$ (1)

General public: $NBgp = Bpp + (P_I-1) (s_g NBg + s_p NBp + s_t NBt + s_{ul} NBul$

$+ s_{gp} NBgp) + (P_F –1) (B_f – I_{mf}) - P_{IUL}(Iml + Oml)$

where, s_g, s_p, $s_{t,}$ s_{gp} and s_{ul} represent respectively average rates of savings of government, passengers, transporters, general public and unskilled labour and

P_{DUL}: Ratio of marginal productivity of labour and project wage rate

P_I: Shadow price of investment

P_F: Ratio of shadow price of foreign exchange and market exchange rate

P_{IUL}: ratio of indirect opportunity cost of labour and project wage rate

The annual economic benefits of DM could be computed as

$NEB = NB_g + NB_p + NB_t + NB_{UL} + NB_{gp}$ (2)

Finally, the estimates of annual flows of social benefits of DM are obtained by applying the estimates of income distributional weights to the incomes accruing to various economic agents from the Metro. Given the estimates of flows of annual economic benefits to the various agents described in Table 9, the net annual social benefits after accounting for income distributional effects of DM could be computed as,

$NSB = w_g . NB_g + w_p . NB_p + w_t . NB_t + w_{UL} . NB_{UL} + w_{gp} . NB_{gp}$ (3)

Two methods are used for the estimation of net present value of economic benefits (NPEB), the social cost-benefit ratio and the social rate of return of DM in this study.

One method assumes that there is a sub-optimal level of savings in the Indian economy and uses the social time preference rate as the rate of discount, the shadow price of investment, the shadow price of unskilled labour consisting of the direct and indirect opportunity cost of unskilled labour employment and the shadow price of foreign exchange in the estimation of annual flows of economic benefits and costs of DM. Another method assumes that there is no sub-optimal level of savings in the Indian economy and uses the rate of return on investment as the social rate of discount, shadow price of unskilled labour consisting of direct opportunity cost and the shadow price of foreign exchange.

Measurement of Economic Costs and Benefits of Metro

The economic costs of the Metro are calculated after excluding the tax component from the financial costs. In a recent study, Murty and Goldar (2006) have estimated the effective state VAT and MODVAT rates on durable commodities in India as 3.8 percent and 6.36 percent, respectively. Since these taxes are levied on the same base, the total effective tax rate applicable for durable commodities in India is roughly 10 percent. The effective tax could be interpreted as the revenue the Indian Government (central and states) gets if there is an increased demand for a commodity by one unit at margin (Ahmad and Stern 1984; Murty and Ray 1989). If the taxes are ad valorem, it implies an increase in the revenue of the government if there is an increase in a rupee worth of expenditure on that commodity. These taxes are also interpreted as shadow taxes. No tax payments are considered on the expenditures incurred by the DM for the employment of unskilled labour. Table 6.13 provides estimates of the economic cost of DM for some select years during its lifetime.

Table 6.13: Components of Economic Capital and O&M Cost

(Rs. Million)

	Capital Cost			O&M Cost	
	Foreign	Unskilled	Domestic	Unskilled	Domestic
Year	Exchange	Labour	Material	Labour	Material
1995	1390	257	695	0	0
2000	5460	1011	2730	0	0
2005	2193	406	1097	156	2671
2010	2852	528	1426	391	6687
2015	0	36	292	478	8180
2020	0	154	1250	606	10369
2025	0	0	0	825	14106
2030	0	0	0	1063	18173
2035	0	0	0	1548	26469
2040	0	0	0	2100	35905

Reduction in the number of vehicles on road

The growth rates of registered cars, two-wheelers, three wheelers, taxis and buses in Delhi are calculated as 9.8, 11, 8, 5 and 7 percent, respectively using data for these vehicles for the period 1971-2002. To calculate the number of vehicles going off the road due to the introduction of MRTS the following exercise is conducted. The registered number of vehicles for each category of these vehicles in Delhi for the period 2002-42 is estimated using the above mentioned growth rates. RITES (1995a) has reported that out of the total registered vehicles, only 28 percent of cars, 40 percent of two-wheelers and 65 percent of taxis and three wheelers are on the roads. It is also reported, depending upon the area and the density of population through which the Metro line passes, that only 30 percent of vehicles on road are influenced by Phase I of the Metro. It is further mentioned that 45 percent of cars, 70 percent of two-wheelers, and 25 percent of buses out of the influenced traffic are diverted to Metro. It is assumed that modes of transport like taxis and three wheelers are on the road by choice and hence they will not be diverted due to the Metro. Table 6.14 reports estimates of diverted traffic to Metro (Phases I and II) for some selected years during 2005-06 to 2042-43.

Table 6.14: Reduction in Vehicles Due to Metro (Phases I & II)

Year	Cars & Jeeps	Two wheelers	Buses	Total
2005-06	50586	284433	3398	338418
2010-11	80731	479286	4767	564784
2015-16	238737	1496497	12388	1747622
2020-21	381006	2521685	17374	2920065
2025-26	608055	4249185	24368	4881609
2030-31	970409	7160124	34178	8164711
2035-36	1548697	12065226	47936	13661859
2040-41	2471600	20330607	67233	22869440
2042-43	2979770	25049341	76975	28106087

The economic benefits from the reduced number of vehicles on Delhi roads due to the Metro could be identified as the following:

- Savings in Foreign Exchange due to reduced Fuel Consumption
- Reduction in Pollution
- Savings in Time for all passengers using Metro and Roads
- Savings in Accidents
- Savings in Vehicle Operating Cost (VOC) due to decongestion for residual traffic
- Savings in Capital and Operating cost of diverted vehicles
- Savings in the cost of Road Infrastructure
- Savings in fuel consumption

There are savings in fuel consumption (inclusive of both CNG and petrol) due to the diversion of a part of the Delhi road traffic to Metro and reduced congestion to vehicles still operating on the roads. There is an inter-fuel substitution of petrol and CNG to electricity that could result in savings of foreign exchange and a reduction of air pollution. Fuel saved due to traffic diverted to the Metro is estimated given the estimates of diverted traffic described above and the annual run and fuel consumption norms of different vehicles. Table 6.15 provides information about the annual run and fuel consumption norms of different vehicles in Delhi. RITES (2005a) has estimated the total reduction in CNG due to the traffic of buses diverted to the Metro (Phases I & II) during the year 2011-12 as 39.65 million kg. Similarly, the fuel saved due to the diverted traffic of cars and two-wheelers is estimated as 138.35 and 25.70 million litres respectively. When these fuel savings are valued at 2004 prices (Rs. 18/kg for CNG and Rs. 38/litre for petrol) the corresponding fuel savings for cars, two-wheelers and buses are Rs. 5260, 9770 and 710 million, respectively.

Table 6.15: Annual Run and Fuel Consumption Norms

Traffic Mode	Diverted Traffic	Fuel Consumption Norm	Daily Run	Fuel Savings	Value of Fuel savings (million)
Cars	164252	13	30	138350586	5257
two-wheelers	985789	35	25	257009274	9766
Buses	9450	18	209	39651154	714

RITES (1995a) has used the following formula which is also used in a study by the Central Road Research Institute (CRRI) for estimating the fuel savings by residual vehicles due to the reduced congestion on Delhi roads after Metro.

$$F_c = A\left(\frac{1}{V_c} - \frac{1}{V_d}\right) + B(V_c^2 - V_d^2).$$

where,

F= savings in fuel consumption (cc/km) due to decongestion c

V= speed of vehicles in a congested situation c

V= speed of vehicles in a decongested situation d

A = 1675.52 for cars and 3904.6445 for buses

B = 0.0133 for cars and 0.0207 for buses

The estimates of savings in fuel consumption for cars and buses calculated by using the above formula are 28.73 cc/km and 91.19 cc/km, respectively. The residual traffic on Delhi roads, in terms of number of cars and buses, for the year 2011-12 are 200752 and 28351 respectively. The total savings in fuel due to decongestion is the product of residual traffic, fuel savings norms given by the above formula, annual run and a conversion factor (cc to litre). The fuel savings during the year 2011-12 due to the decongestion effect for cars and buses are 20714391 ltr and 38510952 ltr, respectively. The RITES study has assumed that the fuel savings of two-wheelers are roughly one-third of cars, which becomes 6835749 ltr.

These savings are valued at 2004 prices as Rs. 390, 130 and 350 million for cars, two-wheelers and buses, respectively.

Fuel savings arising out of the Metro could result in the savings of foreign exchange for the Indian economy given that a very large proportion of domestic demand for petroleum products in India has been met out of imports. A recent study (Murty and Goldar, 2006) on investment planning in India provides an estimate of the shadow price of foreign exchange, which is 10 percent higher than the market exchange rate. Given that there are Rs. 16610 million worth of fuel savings from the Metro in the year 2011-12 valued at market prices or by the dollars spent on the imports of fuels valued at the market exchange rate, the social value of fuels saved at the shadow price of foreign exchange is estimated as Rs. 18271 million.

Reduction in air pollution

Fewer vehicles and the decongestion for the residual traffic on Delhi roads due to Metro could lead to reduced air pollution. The distance saved due to decongestion is estimated by multiplying the time saved with the speed of a vehicle in a decongested situation. An estimate of the pollution reduction by a vehicle in this context could be obtained by multiplying the distance saved by the relevant emission coefficient for different pollutants for each category of vehicle. The emission coefficients for different vehicles as per the Euro II norms are given in Table 6.16. Estimates of reduction in distance traveled every day due to the decongestion effect are obtained for cars, two-wheelers and buses as 9.18 kms, 7.65 kms and 69.72 kms, respectively. Table 14 reports the estimates of air pollution loads due to decongestion avoided due to Metro. The monetary value of these pollution loads are estimated using the estimates of shadow prices of pollutants made in some recent studies in India (Murty and Gulati, 2005; Murty, Surender Kumar and Dhavala, 2006) which are reported in the same table.

Table 6.16: Emission Factors of Vehicles as per Euro II Norms (kg/km)

	PM	NO_x	HC	CO
Bus	0.05	0.87	2.75	0.66
Car	0.03	0.2	0.25	1.98
2- wheeler	0.075	0.3	0.7	2.2
3-wheeler	0.08	0.02	1.45	0.29

Table 6.17: Reduction in Pollution Load due to decongestion and its Monetary Value for the Year 2011-12 with the Assumption that All Vehicles Use EURO II Technology without Metro

Table 6.17: Reduction in Pollution Load due to decongestion and its Monetary Value

Reduction in Pollution Load	HC	PM	NO_X	CO_2
Due to decongestion	643	77	514	8008
Shadow Prices (Rs)	502	4777	6724	448
Value (Rs. Million)	32	0.37	4	4

The vehicular technology complying with Euro II norms or using CNG as a fuel could have similar effects on the air pollution in Delhi as estimated for the Metro. Table 11 above provides estimates of the diverted traffic to the Metro. A major component of the monetary value of reduction in air pollution due to the Metro could be obtained as the savings in the cost of pollution abatement due to the diverted traffic. A recent study by Chatterjee, Dhavala and Murty (2006) provides estimates of the annual cost of Euro II technology for different vehicles.

Table 6.18: Estimates of Monetary Value of Pollution Reduction in the year 2011-12 due to the Metro

Different Mode of Vehicles	Diverted Traffic	Annualized Cost of Conversion of Technology per vehicle (Rs.)	Annualized Incremental Production Cost of Fuel per vehicle (Rs.)	Monetary Value of Reduction in Pollution Due to fewer vehicle (Rs. million)	Monetary Value of Reduction in Pollution Due to Decongestion (Rs. million)	Monetary Value of Total Reduction in Pollution (Rs. million)
Bus	9450	17212	14790	302	11	314
Car	164252	5312	1876	1181	10	1191
two-wheeler	985789	4622	816	5360	18	5379
Total	1159491	27147	17482	6843	40	6883

Savings in passenger time

The savings of travel time of passengers traveling by the Metro instead of by road are calculated as the product of the number of passengers traveled daily and the time saved on the average passenger lead in Delhi. In the case of residual passenger traffic on road, RITES (1995a) has estimated the daily time saving by the passengers due to decongestion using the following formula:

$$T = \frac{D}{S_c} - \frac{D}{S_d},$$

where,

T: time saving on average daily run

D: daily run of vehicles (in km)

S_c: average speed in congested situation (without Metro).

S_d: average speed in decongested situation (with Metro)

The values of the parameters D, S_c, S_d for cars, buses, taxis, 2- wheelers and 3- wheelers, along with the estimates of T for the first phase of the project are summarized in Table 6.19. On the basis of these values, the estimates of value of time/person traveling by buses or other vehicles are arrived at (RITES, 1995a). These are Rs. 5.96/hr and Rs. 7.91/hr, respectively. Passenger time saving per annum for mass transport is then calculated as the product of daily passengers carried, time saved on average lead on an annual basis and the value of time of metro passengers. In the case of other vehicles, the total time saving is given by the product of the total number of passengers on residual vehicles, time saving on average lead on an annual basis and value of time.

Savings due to fewer accidents

The Road User Cost Study (CRRI, 1982) later updated by Dr. L. R. Kadiyali et. al. in association with the Loss Prevention Association of India provides estimates of the cost of various accidents on road. Components like gross loss of future output due to death/major injury, medical treatment expenses, legal expenses, administrative expenses on police, insurance companies and the intangible psychosomatic cost of pain were included in the estimation. In the case of buses and other public vehicles, the loss due to lay off period and unproductive wages paid to the crew are also included. The costs (at 2004 prices) under different heads are reported in the Table 6.21.

Mode	D (km)	S_d (km/hr)	S_c (km/hr)	T (hr)
Bus	209	14	10.5	4.98
Car	30	17	13	0.54
Taxi	80	17	13	1.45
3- wheeler	100	17	13	1.81
2- wheeler	25	17	13	0.45

Table 6.19: Values of Parameters D, S_d , S_c and T

	Bus	Metro
Daily passengers carried (million)	3.3	3.2
Time saved on average lead (hours)	0.21	0.31
Value of time per passenger (Rs.)	5.96	5.96
Value of daily time saving (Rs. million)	4.13	5.91

T

Table 6.20: Time Savings and Value of Time for Passengers

Different Mode of Vehicles	Diverted Traffic	Annualized Cost of Conversion of Technology per vehicle (Rs.)	Annualized Incremental Production Cost of Fuel per vehicle (Rs.)	Monetary Value of Reduction in Pollution Due to fewer vehicle (Rs. million)	Monetary Value of Reduction in Pollution Due to Decongestion (Rs. million)	Monetary Value of Total Reduction in Pollution (Rs. million)
Bus	9450	17212	14790	302	11	314
Car	164252	5312	1876	1181	10	1191
two-wheeler	985789	4622	816	5360	18	5379
Total	1159491	27147	17482	6843	40	6883

Table 6.21 The costs (at 2004 prices) under different heads

These studies have found that the following relationships exist between the number of vehicles affected and the number of persons killed and injured in road accidents.

$Y_1 = 49.43X + 750.42$ $R^2 = 0.89$

$Y_2 = 257.04X + 3181.41$ $R^2 = 0.90$

where,

X: number of vehicles affected in lakhs

Y_1: number of persons killed in road accidents in a particular year

Y_2: number of persons injured in road accidents in a particular year

Cost Component	Value (Rs.)	Reduction in injuries, fatalities and damage to vehicles	Compensation for 2011-12 (Rs. million)
Cost of fatal accident	437342	573	250
Cost of major accident	64256	2980	190
Cost of damage to cars in road accidents	9763	236	2.3
Cost of damage to two wheelers in road accidents	2286	1416	3.2
Cost of damage to buses in road accidents	32818	14	0.4

Table 6.22: Compensation Values

Assuming that the above relationships hold and given the number of vehicles that are expected to go off the road (diverted traffic) due to the Metro, the reduction in fatalities and accidents is estimated. For instance, in the year 2011-12, the diverted traffic for cars equals 164252, while the corresponding values for two-wheelers and buses are 985789 and 9450 respectively. The values of reduction in fatalities and injuries, as derived from the above equation are reported in Table 18. The total benefit owing to the lesser number of fatalities and injuries is reflected in the total savings in compensation paid. Next, the study also reports the estimated relationship between the number of accidents resulting in damage to property and number of vehicles on road as,

$$Y = 143.63X + 3345 \quad R^2 = 0.84$$

where,

X: number of vehicles on road

Y: number of vehicles causing damage to property

Given the above relationship and the data on the mode wise distribution of accidents in Delhi over the years, the reduction in accidents for different types of vehicles is estimated and reported in Table 18. The estimates of cost of damage to cars, buses and two-wheelers in road accidents, as reported in the above table are used to estimate the total savings in compensation paid due to damage caused vehicles.

Savings in vehicular operating costs due to the decongestion effect

Annual vehicle operating cost is substantially reduced due to the higher speed of vehicles and consequently lesser hours on road. It is estimated as the product of the residual traffic, time saved on average lead per vehicle annually and the vehicle operating cost per hour. According to RITES (2005b), the value of this component for the year 2011-12 is Rs. 15040 million.

Savings in Capital and Operating Cost of Diverted vehicles

Reduction in the capital and operating cost of vehicles due to the introduction of the MRTS is given by the product of the diverted traffic stream, the annual run and the VOC/V-km. The estimated value of this component for the year 2011-12 is Rs. 17677 million.

Economic Evaluation of Metro

The methodology described in Section III is used for the economic evaluation of the Metro. Two approaches are used for the analysis. One approach maintains that there is a sub-optimal level of savings in the Indian economy and therefore the social time preference rate is lower than the rate of return on investment and there is a social premium on investment. This approach is similar to the standard UNIDO method (Dasgupta, Sen and Marglin, 1972) for investment project evaluation. Another approach assumes that the level of savings in the Indian economy is optimal and there are no distortions in the capital market so that the rate of return on investment or the market rate of interest could be taken as the social time preference rate. Both the approaches recognize that distortions still exist in the markets for unskilled labour and foreign exchange so that their market prices are different from the shadow prices. However, in the case of unskilled labour, its shadow price consists of the direct and indirect opportunity cost of unskilled labour employment on investment projects in the first approach while it constitutes only the direct opportunity cost in the case of the second approach. The direct opportunity cost constitutes the marginal productivity of unskilled labour in the alternative employment say in agriculture while the indirect opportunity cost is due to the social value of loss in savings or investment due to labour employment. A recent study commissioned by the Planning Commission, Government of India (Murty and Goldar, 2006) has obtained estimates of the social time preference rate and the rate of return on investment for the Indian economy as 8 and 10 percent, respectively. It has also made the estimates of 36 percent and 10 percent social premium on investment and foreign exchange respectively. It provides an estimate of the marginal productivity of unskilled labour in agriculture as Rs. 48 per day and an estimate of the shadow wage rate consisting of the direct and indirect cost of unskilled labour employment as Rs. 60 for the Indian economy. This study also provides some estimates of the income distributional weights pertaining to incomes of people belonging to different income groups in the Indian economy. These estimates of national parameters for the investment project evaluation in India are used for the economic evaluation of the Metro.

The economic agents affected by having the Metro operational in Delhi could be identified as government, passengers, general public, private transporters and unskilled labour. As explained in Section III these agents get incremental benefits and incur incremental costs due to Metro.

The Government gets fare box revenues, revenues from property development and advertisements and tax revenue on the goods and services bought for the investments and operation and maintenance of the Metro while it suffers revenue losses due to the displaced public buses. It incurs the investment and operation and maintenance cost of the Metro while it saves the cost on road infrastructure and the capital and operating cost of displaced public buses. The net benefits for the government during the year 2011-12 are estimated as Rs. 31760 million at 2004 prices.

The Passengers gain to the extent of the difference between the fares paid to buses in the absence of the Metro and the fares charged by the Metro. For instance, during the year 2011-12, the fare box revenue to the displaced buses should have been Rs. 10460 million while that of the Metro is estimated at Rs. 35280 million. Therefore, passengers have incurred an additional cost of Rs. 24830 million due to these fare differences. However, there is a time saving for the passengers due to the Metro. As explained in Section IV, there is both time saving travelling on the Metro as also time saving to the residual traffic on the roads due to the reduced congestion. During the year 2011-12, these savings are together estimated as Rs. 22090 million. There are also benefits due to a reduction in accidents to the passengers due to the functioning of the Metro, which are estimated as Rs 448 million during the year 2011-12. The net benefits to the passengers from the Metro are estimated as Rs.22440 million during the year 2011-12.

The Private transporters lose the revenue from displaced private buses but at the same time save on their capital and operating costs. These are estimated as Rs. 9410 and Rs. 6550 million, respectively resulting in a net loss of Rs. 2860 million to the private transporters during the year 2011-12.

The Unskilled labour employed on the construction and maintenance of Metro gain to the extent of the difference between the project wage rate and the wage rate in an alternative employment in India. Murty and Goldar (2006) provide an estimate of the marginal productivity of unskilled labour in agriculture as Rs. 48 while on the average, the industrial wage for unskilled labour in India is Rs. 120 per day at 2004-05 prices. Assuming that the unskilled labour cost constitutes 10 percent of investment cost and 5 percent of operation and maintenance cost of the Metro, the benefit to unskilled labour is estimated as Rs. 316.4 million during the year 2011-12.

The General public representing the Indian society receives the benefits of social premium on investment and foreign exchange and the environmental benefits of reduced pollution due to the Metro. There are foreign exchange costs and foreign exchange benefits from the Metro. Foreign exchange cost accounts for 60 percent of the investment cost of the Metro. There are foreign exchange benefits to the extent of reduced fossil fuel consumption due to a change in the mode of transport. Murty and Goldar (2006) have estimated a 10 percent social premium on foreign exchange for the Indian economy. The net benefits to the general public from the Metro arising out of the social premium on foreign exchange is estimated as Rs. 1203.3 crores during the year 2011-12.

There could be incremental benefits or losses of savings due to the Metro in the Indian economy depending upon the propensity to save of different agents affected by the project. Without accounting for the social premium on savings, the government, passengers, private transporters and the public get total net benefits worth Rs. 52550 million in the year 2011-12. Assuming a savings rate of 29.10 percent on an aggregate in the Indian economy in 2011-12, the incremental savings due to the Metro in the Indian economy works out to be Rs. 15290 million in the same year. Given an estimate of the social premium on investment as 36 percent (Murty and Goldar, 2006), the public receives benefits worth Rs. 5500 million on this account. It is assumed that the propensity to save of unskilled labour is zero in this estimation.

Also the public receives benefits from the reduced air pollution due to the Metro. Section IV describes a method of estimating these benefits and provides an estimate of these as Rs. 6883 million in the year 2011-12. Therefore, public receives net benefits worth of Rs. 14260 million in the year 2011-12 due to Metro.

The net present economic benefits (NPEB) and the economic rate of return of the Metro are estimated after taking into account all the flows of benefits and costs described above for the time period 1995-2041 during the life of the project. An estimate of NPEB of the Metro using the first approach and an 8 percent rate of discount is Rs. 432387.5 million while the estimate using the second approach and a 10 percent rate of discount is Rs. 232050.7 million.

Table 6.23: Net Benefit to Various Agents during the year 2011-12

Agents	1st approach	2nd approach
Govt	31764	31767
Public	14260	8086
Unskilled labour	316	316
Passenger	22441	22441
Transporter	-2859	-2859

Table 6.24: Estimation of NPEB for Different Agents

(Rs. Million)

Agents	1st approach	2nd approach
Govt	225483	124502
Public	159458	67643
Unskilled labour	7049	5508
Passenger	79553	55615
Transporter	-39155	-21217

Net Present Economic Benefits and Economic Rate of Return of Metro

The estimates of the economic internal rate of return (IRR) corresponding to the first and second approaches are 23.86 and 23.88 percent, respectively. Table 6.25 provides the estimates of NPEB and the economic rate of return of the Metro at different levels of approximation to the social benefits.

Equity and Social Benefits of Metro

The Metro in Delhi has resulted in significant income distribution among various economic agents affected by it. As shown in Table 20, while on the one hand, the government, unskilled labour, public and the passengers have gained, on the other private transporters have suffered substantial losses. The social benefits of the Metro could be estimated by assigning the appropriate income distributional weights to the incremental changes in incomes of these agents due to the project. Murty and Goldar

(2006) describe a method of estimating these weights and provide their estimates for the incomes of people belonging to different income classes in the economy.

Table 6.25: Estimation of NPEB and IRR

	1st approach		2nd approach	
With different scenarios	NPB (Rs. Million)	IRR (%)	NPB (Rs. Million)	IRR (%)
At market prices	265880	21.51	158900	21.51
With shadow price of unskilled labour only	272929	22.30	164408	22.30
With shadow prices of unskilled labour and	294358	22.56	176330	22.56
foreign exchange only				
With shadow prices of unskilled labour, foreign exchange	324155	22.54	176330	22.56
and investment				
With shadow prices of unskilled labour, foreign exchange	432387	23.85	232051	23.88
and investment and environment services				

Table 6.26provides estimates of the income distributional weights used in the estimation of the social benefits of the Metro which are computed as follows:

where, $D = (Y_i / \bar{Y})^v$

Y_i: income of the i^{th} economic agent

$\bar{Y}$: per capita gross domestic product of India

v: elasticity of social marginal utility of income with respect to income.

Distributional weights are computed assuming that the public and government are assigned to the income class having a per capita income equal to the per capita GDP of India. Passengers are assigned to the income class having a per capita income equal to the Delhi state per capita GDP while transporters are assigned to the income class having a per capita income equal to twice the Delhi per capita GDP. Unskilled labour is assigned to the income class having a per capita income equal to the per capita income of an unskilled labourer's family. Murty and Goldar (2006) provide an estimate of "v "for the Indian economy as 1.4. The gross domestic per capita income for All India and Delhi state are Rs. 23484 and Rs. 50991 in the year 2002-04, respectively.

Table 6.26: Income Distributional Weights

Agents	Income distributional weights (D_i)
Govt of India	1
General public	1
Passengers	0.34
Private Transporters,	0.13
Unskilled labour	1.87

The estimated NPSB of the Metro after accounting for the income distributional effects is Rs 419979.6 million using the first approach while it is Rs. 218512.4 million using the second approach. The corresponding IRR is approximately 22.70 percent for the first approach, while it is 22.60 percent for the second approach.

6.1.3 Mono Rail

NEW DELHI: It's official. Monorail is coming to town. Even before completion of a feasibility study, Delhi government has decided to implement the transport system as a 60-km feeder service to various stations of Delhi Metro.

This, despite the fact that internationally, the system has only been implemented in amusement parks or connected tourist destinations. Considered an eco-friendly mode of transport, monorail is usually an elevated network which runs on a single track and has tube tyres. It has stations similar to our elevated Delhi Metro lines, with access from the road and the track overhead usually aligned to the central divide. Though the passenger-carrying capacity of monorail is less than that of the Metro, it is considered a cheaper option, at Rs 35-40 crore per kilometre.

Delhi transport minister Haroon Yusuf said told TOI that "it is final that we will introduce monorail. It is a good system and we are just about to finalise details of the finance model. Our consultant is working out whether we should have a public-private partnership or put it in private hands. But one thing is absolutely certain – monorail has to be introduced." According to sources, the government is planning to take up a 15-km stretch as a pilot project. The project is likely to be initiated in the Walled City – the transport minister’s constituency. The pilot project will take about two to three years. Delhi government is considering whether or not to ask the Centre for funds. "Our consultant, who is a former RITES chairman, is working out models. We are exploring the possibility of following a model similar to Delhi Metro," Yusuf said. Delhi is likely to follow Kuala Lumpur, where the system connects a few parts of the city. Ircon International Limited, a government undertaking, has tied up with Monorail Malaysia Technology (MMT) to implement the system in the capital.

6.2 Improvement in Fuel Quality

Fuel quality is directly responsible for the quantity and quality of vehicular emissions. The Central Pollution Control Board has played a major role in emission related fuel quality improvement. The specifications for emission related fuel quality is presented in following table 6.27

Benzene and aromatics in petrol

Due to high level of benzene in atmosphere, benzene content of gasoline needs to be reduced to 1% (v/v) or lower as in other countries. With the reduction of benzene in gasoline (<1%) it is possible to achieve significant reduction in benzene emission from exhaust. Benzene and PAH emission also depend upon the aromatic content of gasoline.

Therefore, in addition to reduction of benzene, it is also necessary to reduce the aromatic content in petrol.

Table 6.27 Emission Related Fuel Quality Specification

Fuel	**Parameters**	**Pre 1996**	**1996**	**2000**	**2005 (Proposed)**
Motor-gasoline	Lead, g/litre (Max)	0.56	0.15	0.013	0.005
	Benzene, % V/v (Max)	No limit	5	3	1
	Sulphur, % W/w (Max)	0.25	0.20 (leaded) 0.10 (unleaded)	0.10	0.03
Diesel	Sulphur, % W/w (Max)	0.5	0.5	0.25	0.05
	Cetane number (Min)	42	45	48	50
	Density, Kg/M^3	No limit	820-880	820-860	820-855

Reducing Benzene Content In Motor Gasoline

Benzene is a proven carcinogen. The most significant health effects from a short or long term exposure to benzene are haemotoxicity, immunotoxicity, neurotoxicity and carcinogenicity.

Benzene in the crude oil is present at levels upto 4 g/l. Its concentration varies from one source to another. In India, Benzene content in motor gasoline varies from 3-5% by weight.

Although Benzene is also emitted from industrial activity, about 80 to 85% of benzene in atmosphere comes from automobiles. In heavy traffic area, upto 40 to 50 ug/m^3 of Benzene in the ambient air has been observed.

About 80-90% of the Benzene from automobile sector is emitted from the exhaust. About 10-20% are from evaporation while 3-6% are from transportation, delivery and distribution at petrol stations. Most part of benzene in gasoline is oxidised during combustion while some part are emitted through exhaust. Some portion of benzene is formed from the other aromatics by process of dealkylation during combustion. On an European vehicle fuelled with gasoline containing 3% by wt of benzene and 30% by wt of other aromatics, it has been found that 44% of the benzene survived combustion and 56% was created during combustion from other aromatics.

Average benzene emission of 32 mg/km out of 1130 mg/km of HC has been measured on American automobiles equipped with catalytic converter in FTP cycle. European automobiles without catalytic converter emit about 270 mg/km of benzene in ECE cycle. Benzene exhaust emission (B.E.E.) can be estimated by following equation, BEE mg/km = [1.884 + (0.949 x % Benzene) x 0.113 + (% aromatics - % of Benzene)] x 1.609 By this equation, it can be estimated that if benzene control is reduced from 5% to 3% there will be 35% reduction in the exhaust emission of Benzene.

In USA, Europe and Japan, benzene content in motor gasoline has been reduced to 1%. In India, the benzene content of 5% has been prescribed which will be reduced to 3% from year 2000.

Sulphur Content in Diesel

Sulphur in diesel has direct effect on SO_2 and particulate emission and indirectly on other pollutants due to its poisoning effect on catalytic converter. In European countries, sulphur content in diesel has been reduced to 0.05% from 1996 and it will be further reduced to 0.005 from the year 2000.

Reformulated gasoline

Reformulated gasoline with the use of oxygenates and additives etc. help reducing pollution load from on-road vehicles. According to a study commissioned by CPCB, 3-5% ethanol can be used in petrol without affecting the engine performance and with the attendant benefits in terms of emission control.

Tightening of emission norms

The emission norms effective from 2005 need to be further tightened to offset the increase of pollution load due to exponential growth of vehicles. It is time to bridge the gap between Euro norms and Indian norms. Euro IV norms for petrol vehicles and diesel passenger cars and Euro III norms for heavy diesel vehicles may be a preferred target for 2005.

6.3 Traffic Management System

Well planned Traffic management system results in better mobility level on road by providing higher journey speeds and reduced delay at intersection thereby bringing significant reduction in fuel consumption and emission. Automatic traffic control, signal optimisation, tidal flow and removal of encroachments are among the important components of traffic management system. This will reduce the congestion and consequently pollution. Frequent digging of roads and construction work also leads to congestion and pollution, which can be minimised through proper coordination with traffic police.

6.4 Comprehensive Inspection and Certification System

It is a system to reduce the pollution by requiring regular inspection and maintenance of motor vehicles already plying on roads. It identifies those in-use vehicles that need maintenance and repair because they pollute more than the new vehicles. The system helps in reducing the air pollution. Such system is widely used in other countries and it has been possible to reduce about 30-40% of pollution loads by proper inspection and maintenance of vehicles. Such facilities for thorough inspection and maintenance of vehicles are required in different parts of the country.

6.5 Phasing Out of Grossly Polluted Vehicles

Pre-1990 vehicles emit more than ten times pollutants than the vehicles meeting Euro I norms (India 2000 norms). In Delhi, more than 15 year old commercial vehicles are not allowed to ply on roads. Similarly, de-registration of all older vehicles should be made effective so that the grossly polluting vehicles are phased out.

6.6 Improvement in Vehicles

In India, majority of vehicles is of two stroke engines. Although the two stroke engine technology for 2 or 3 - wheelers has been upgraded to some extent there is not much improvement in control of hydrocarbons and particulate (due to combustion of lube oil). Hence, it is necessary to consider as to whether 2-stroke technology should be replaced by 4-stroke technology for reducing the emission specially in terms of hydrocarbons and particulate matter apart from increased fuel efficiency in 4-stroke engines.

On Board Diagnostic System

The On Board Diagnostic System (OBD) electronically records the fault and their causes in combination with various Diagnostic Strategies to enable vehicle owner / driver to take corrective action. This is one of the requirements of emission regulation in USA and it will be followed in Europe from year 2000 which will be a part of Euro III norm for 2000.

Checking Fuel Adulteration

Adulteration of fuel plays a major role in emission of pollutants from on roads vehicles. Effective measures are required to prevent adulteration of fuel.

Evaporative Emission Control

To minimise evaporation losses of fuel and consequent pollution, adequate preventive steps need to be taken during storage, loading, unloading and distribution. Vapour recovery system in the filling stations is yet another important measure for reducing evaporative losses.

Technology Options to Curb Vehicular Pollution

Fuel Injection Systems.

The Automotive emissions are controlled in three way more complete combustion so that there are less by products. The second is to reintroduce excessive hyd ine for ombustion (may suit for two stroke engines) itional area for xidation or combustion to occur. This additional th

pressure reduces concentration of increases concdecreases flame temperature, resulting in considerable reduction in the concentration of NOx. The effect is greater for the leaner vapor. s. One is to promote a rocarbons back into the eng c and the third is to provide an add area is called a .catalytic converter.. The chemical theories and practice of catalytic conversions were known for many years, but catalyst technology has grown since the mid 1970s. Studies show a four to six-fold reduction in total emission and a 40-fold reduction in CO emission at constant speeds. Catalytic converters (Figure.2) however do not reduce CO_2 emission, a greenhouse gas. The catalytic converter is installed in the exhaust line, between the exhaust manifold and the muffler, and makes use of precious metal that act as a catalyst. The pollutants thus changed from harmful gases to harmless ones before they are let into environment through the tail pipe.

Generally a catalytic converter does not require any maintenance or servicing. The converter would need replacement if leaded fuel is used or if some accidental damage occurs. In India, the problem faced is of a different kind. It is evident that for catalytic converter to be effective the fuel undergoes effective oxidation in catalytic converter.

The catalytic converter manufacturers in India claim that the fuel available is of poor quality and this makes it difficult for them to meet required emission standards. It is a valid point they make, although part of the blame for slow up gradation to advanced one and decidedly more green technology lies with them. Heavy government subsidies on kerosene only promote its use as an adulterant in fuel. The converter action when simplified involves two main reactions, oxidation of unburned hydrocarbons and CO to give CO2 and reaction of NOx and CO to form N2 and CO2. Because the two opposing reactions take place simultaneously there is optimal oxygen content. This level is maintained by fuel injection systems through adjustments to air fuel ratio. Some catalytic converters use an .oxidation. catalyst; which usually consists of pellets or a honeycomb made of platinum or palladium. The platinum is used as a catalyst to reduce hydrocarbons and carbon monoxide. Through the catalytic action, the hydrocarbons and carbon monoxide are .burned. at a 482 F (209 ^{o} C) carbon dioxide. The converter has the maximum effect when operating temperature in it exceeds to 660 F (350 ^{o} C). This type of catalytic converter needs an input of oxygen. So oxygen is usually injected into the cylinder head or directly into the exhaust header or manifold.

Three-Way Catalytic Converter

These converters have binary metals such as platinum and rhodium, which reduce nitrogen oxides along with oxidation of HC and CO. The three-way converter operates in two stages; the first converter stage uses rhodium to reduce the NOx in the exhaust into N2 and CO2. In the second stage platinum or palladium acts as into harmless water and CO2. For supplying the oxidation catalyst to change HC and CO oxygen required in the second stage, air is fed into the exhaust after the first stage. The catalyst allows the oxidation of exhaust gases at a much lower temperature than in combustion chamber.

Conversion of Two strokes Engine into Four Stroke Engine

In Delhi, two-wheelers account for about two Third of the total vehicle pollution proportion of overall automobile pollution is due to large number of two-wheelers /three wheelers fitted with 2-stroke engines. Because of the inherent drawbacks in the design of 2- stroke engines, 2-wheelers emit about 20-40% of the fuel un-burnt/partially burnt. At present, two-wheelers generate more than 70% of the hydrocarbon emissions and nearly 40% of the CO emissions in Delhi. As these emissions are less visible than SPM, the general public is not aware of the role of 2-wheelers in the deteriorating air quality to reduce pollution scenario from such vehicles 2-stroke engines need to be replaced by 4-stroke engines. It is one of the alternative technologies for reducing vehicular pollution and aimed to reduce pollutants from exhaust of smaller 2-stroke engine fitted vehicles such as scooters and motorcycles /three wheelers (Table 6.28).Relative to carbureted 2-stroke engines, the main benefits offered by carbureted 4-stroke engines are:

- Misfire-free operation.
- Reduced fuel consumption and CO2 emissions.
- Reduced HC emissions.

Table 6.28 Emissions of various categories of vehicle and engine parameters

Motorcycle	Engine Type	Enginedisplace- ment, cm^3	Fuel Economy Km/l	Emission, g/km		
				CO	HC	NO_x
Kawasaki KE-175	2-stroke	174	24.2	24.16	7.48	0.02
Suzuki TS-100	2-stroke	98	29.2	13.19	7.09	0.03
-	2-stroke	200	30.0	12.2	4.8	-
Honda XL-125	4-stroke	124	42.3	11.60	0.78	0.13
-	4-stroke	150	36.2	15.8	0.93	-

6.7 Alternative Fuels

The stock of fossil fuels diminishing throughout the world and demand is increasing, thereby compelling us to search for a basket of alternative fuels to derive energy to cater to our needs. The future of gaseous/alternative fuels depends on the maximum of polluting emission allowed, the technology available and the cost of concepts developed. The alternatives to petroleum-based fuels must meet the following criteria, if they are going to be used widely for transportation.

- Technical acceptability

- Economically competitive

- Environmentally acceptable

- Safety & availability.

Based on the above criteria, several alternate fuels have been considered from time to time all over the world as low cost substitutes for gasoline and diesel. Lately they have gained importance as clean fuels. The prominent among these are, Bo diesel, electric fuel, ethanol, hydrogen, methanol, natural gas (CNG/LNG), propane (LPG), DME, P-series and solar fuels.

6.8 HYBRID ELECTRIC VEHICLES

Hybrid Electric Vehicles (HEVs) combine two or more energy conversion technologies (e.g., heat engines, fuel cells, generators, or motors) with one or more energy storage technologies (e.g., fuel, batteries, ultracapacitors, or flywheels). The combination of conventional and electric propulsion systems offers the possibility of greatly reducing emissions and fuel consumptions, while giving consumers both the extended range and convenient refueling they expect from a conventional vehicle. HEVs can either have a parallel or series design. In a parallel design, the energy conversion unit and electric propulsion system are connected directly to the vehicle's wheels. The primary engine is used for highway driving; the electric motor provides added power during hill climbs, acceleration, and other periods of high demand. In a series design, the primary engine is connected to a generator that produces electricity. The electricity charges the batteries and drives an electric motor that powers the wheels.

Advantages of HEVs:

The advantages of HEVs are:

- HEVs are two or three times more fuel efficient than conventional vehicles.
  - Good emission benefit.

- Extended vehicle range.
- Easy and rapid refueling.
- Compensates the shortfall in battery technology.
- Application of regenerative braking helps minimize energy loss.
- HEVs can run on alternative fuels thus can reduce the dependency on fossil fuels.

Disadvantages of HEVs:

Hybrid electric vehicles enjoy many advantages overruling the demerits associated with it, if any. As these vehicles are very recently introduced in the market, data on their on-road performance and servicing requirements are yet to be analysed.

Indian Initiative on HEVs:

In India, Ashok Leyland has developed a model hybrid bus in collaboration with ER&DCI. This hybrid bus has been displayed in the 2002 Auto Expo. Indian manufacturers are investing in R&D to bring out some HEV models. A mini electric car REVA is also rolled down, which needs the government support for proving most economical.

CONCLUSIONS

Delhi figures prominently in the world environment map for the simple reason that it is one of the most polluted cities in the world caused by spectacular vehicular growth in the past 2-3 decades. Incidentally, few years back it was acclaimed as one of the greenest capital also. Our results and analysis however shows that the imposition has not led to concomitant improvement in ambient air quality. There exist a number of explanations for this lackluster result.

- Even with stricter enforcement, a regulatory approach based on emissions standards is fated to result in greater pollution discharge if the number of sources increases, unless the standards are made more stringent.

- Most instruments fail unless people are made aware of the benefits. That could be the other reason for instruments not showing intended impact.

- If instruments require scrappage of old vehicles, then simply mandating sales of new clean vehicles does not fully address the ambient air quality problem. This is because it still remains unknown who will purchase the vehicles, where will they be living (highly polluted or cleaner regions), or how much will they drive the vehicles once purchased.

- As mentioned earlier, many countries like Singapore, Chile etc. have initiated a shift from the dedicated fuel efficiency and atmospheric pollution regulation to pure transport policies like road pricing, parking and collective transport. This shift has multi-faceted benefit as it addresses the pure transport related externalities like congestion, traffic accidents etc. besides, having a large beneficial impact on air pollution.

In fact, the containment of vehicular pollution requires an *integrated approach*, with many essential components:

(i) improvement of public transport system;

(ii) optimization of traffic flow and improvement in traffic management (e.g., area traffic control system, no-traffic zone, green corridors, removal of encroachment on roads, regulation of construction activities and digging of roads)

(iii) comprehensive inspection and certification system for on-road vehicles;

(iv) phasing out of grossly polluting units;

(v) fuel quality improvement (e.g., benzene and aromatics in petrol, reformulated gasoline with oxygenates/additives, reduction of sulphur in diesel);

(vi) tightening of emission norms (e.g., EURO-III);

(vii) improvement in vehicle technology (e.g., restriction on the 2-stroke engines)

FUTURE SCOPE OF WORK

The present study and the results obtained have policy implications for Delhi that have embarked upon widespread use of CAC to control air pollution. As long as NCR (national Capital Reason) consider the problems of air quality and transport related externalities as separable, the control of air pollution will not be achieved. Hence a complete study on vehicle using Delhi as corridor, pollution emitted by industries in NCR region are require to be done to improve the air quality of NCR and hence Delhi.

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