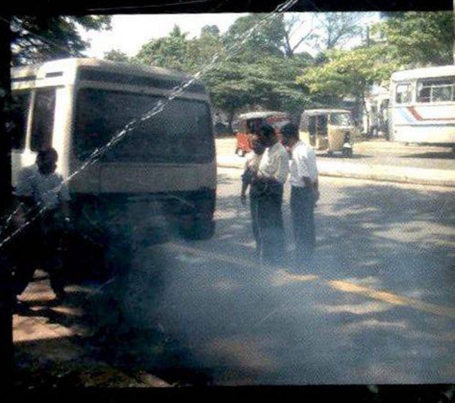
ENV GA 09

Urban Air Quality Management in Sri Lanka







AIR RESOURCE MANAGEMENT CENTER (AirMAC)

MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES
SRI LANKA.

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FOREWORD

On be-half of the Ministry of Environment and Natural Resources of Sri Lanka I am pleased to present the output of the Urban Air Quality Management Project, implemented through assistance of the World Bank.

The effects of air pollution to people's health are numerous. These include asthma, lung ailment, and heart attacks. Children and elderly group is most vulnerable. It affects the household by increasing the health expenses. The effects of air pollution on the environment include unclean air to breathe, climate change, polluted surrounding, and withered plants and trees. Lack of visibility of air, increased the number of accidents.

Epidemiological studies show that the air pollution in developing countries accounts for tens of thousands of excess deaths and billions of dollars in medical costs and lost productivity every year. These loses, and the associated degradation in quality of life, impose a significant burden on people in all sectors of society, especially the poor. Gasoline vehicles are the main source of hydrocarbon and carbon monoxide, while diesel vehicles are a major source of respirable particulate matter. Two-stroke motorcycles and 3-wheelers are also major contributors to emissions of respirable particulate matter. Gasoline and diesel vehicles are among the main source of toxic air contaminants in most cities and are probably the most important source of public exposure to such contaminants.

Therefore, reduction and control of vehicular emissions require comprehensive strategy, which requires emissions standards for new vehicles, cleaner fuels, emissions standards and inspection & maintenance program for in-use vehicles, vehicle importation policies, traffic & demand management measures; and also institutional development, awareness, education and training. The Ministry of Environment and Natural Resources with the financial support of the World Bank took an initiative to strengthen the institutional and policy framework for the urban air quality management in Sri Lanka as a measure to arrest the deteriorating trend of urban air pollution and its accompanying adverse health effects. These initiatives include measures to reduce motor vehicles emissions, measures to improve the quality of motor fuel available in Sri Lanka, and measures on fiscal policies on motor fuels.

The vehicle emission control component was expected to strengthen the capacity of the Department of Motor Traffic, the planning Unit of the Ministry of Transport, and the Central Environmental Authority for vehicle emission control, and to assist in revising in-use vehicle emission standards, establishing an inspection and maintenance programme, limiting the number of vehicles on road, awareness raising, and exploring innovative partnership arrangements and financing mechanisms. This report presents recommendations on vehicle emission standard setting, vehicle inspection, and vehicle importation policy that could be implemented to address urban air pollution in Sri Lanka.

Fuel quality improvement component include measures to improve the quality of motor fuel available in Sri Lanka. This section presents the major findings and recommendations of the motor fuel quality improvement component of the project. It present International trends in fuel quality specifications, Proposed improved future transport and fuel quality, Refining investment – Case Studies, and Impact on fuel quality on exhaust emission under the major findings. After careful review of all the information developed on refinery investment, fuel quality improvements and their impacts on emissions the report also recommended for upgrading the refinery and improving its flexibility in satisfying tighter gasoline and diesel fuel specifications

Fiscal Policies on Fuels and Vehicles component include measures on fiscal policies on motor fuels. The objective of the fiscal policies component is to investigate the effects of fuel pricing on household welfare, vehicle emission and urban air pollution. Fuel taxation and pricing have impacts, which cut across a number of sectors and issues. The price of gasoline was kept high in Sri Lanka to cross-subsidise other fuels, particularly diesel and kerosene. This in turn has lead to owners of light-duty vehicles switching from gasoline to diesel, reducing an important source of revenue for Ceylon Petroleum Corporation (CPC). Moreover, there is increasing evidence that diesel emissions are much more harmful than gasoline emissions and hence increasing the share of diesel vehicles has an adverse impact on public health in urban areas. Increasing the price of diesel to stem this trend, however, would affect a number of sectors using diesel such as freight transport, agriculture and power generation. Also it presents the results of an extensive analysis undertaken on alternative options for pricing diesel, petrol, and kerosene and levying duties on different fuels and vehicles. The report presents recommendations on fiscal measures to address urban air pollution in Sri Lanka.

Studies carried out under the Urban Air Quality Management Project will be useful in many ways. It will be useful for the implementation of vehicle emission control programme in Sri Lanka. On the other hand it will be useful for suppliers of petroleum products to take suitable actions to improve fuel quality in Sri Lanka. And also will be a useful reference for making fiscal policies towards improvement of air quality in Sri Lanka.

Thosapala Hewage
Secretary
Ministry of Environment and Natural Resources

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This report summarizes the findings of the Urban Air Quality Management Project of the Ministry of Environment and Natural Resources implemented with assistance from the World Bank through an IDF grant. I owe very special thanks to the World Bank for the assistance.

Mr. Christopher S. Weaver and Mr. Lit-Mian Chan of Engine, Fuel, and Emissions Engineering, Inc, USA, served as international consultants of the vehicle emission reduction component studies. Ms. Maria Camarsa and Dr. Robert McKinven of Enstrat International Limited, served as the international consultants of the motor fuel quality improvement studies. And Prof. David Newbury and Mr. Cliff Pattern of Cambridge Economic Policy Associates, served as international consultant of the component of fiscal policies on fuels and vehicles in Sri Lanka. I believe that their international experience enriched the quality of this study and I thank them for their valuable contributions made within tight deadlines.

I also wish to convey my thanks to Mr. Thosapala Hewage, Secretary, Ministry of Environment and Natural Resources, Mr. W.R.M.S. Wickramasinghe, Additional Secretary, Ministry of Environment and Natural Resources Mr. Faiz Mohideen, Deputy Secretary to the Treasury. Their guidance and advice were invaluable for the successful completion of this study.

I also warmly acknowledge the contributions made by Ms. Kesanya Lvovsky, Task Leader of this project, Ms. Masami Kojima, Specialist, Dr. Sumith Pilapitiya, Task Manager (Local), and Ms. Esha Ramachandran all of the World Bank team for providing resources and support to complete this project successfully.

I extend my special thanks to Sri Lanka Thermo Fluid and Energy Group of the University of Moratuwa, Local Consultant of the vehicle emission reduction component, Mr. D. Chandrasekara, Refinery Adviser, Ceylon Petroleum Corporation, Local Counter Part of the motor fuel quality improvement studies, Dr. Sunil Chandrasiri, Local Consultant of the component of fiscal policies on fuels and vehicles, Dr. D.S. Jayaweera, Deputy Director, Ministry of Transport, Highways and Civil Aviation, Mr. C.K. Amarathunga, Deputy Director, Central Environmental Authority, Dr. A. Mallawatantri, Director, US-Asia Environmental Partnership Program, Dr. Ruwan Wijayamuni, Chief Medical Officer, Colombo Municipal Council, Mr. Gamini Senarath, Commissioner, Department of Motor Traffic, Mr. A.W. Dissanayake, Assistant Commissioner, Department of Motor Traffic, Mr. S.M. Wickramasinghe, SSP, Traffic Police, Mr. Neel Hapuhinna, Project Director, Vehicle Emission Testing Certificate Programme, Mr. Piyadasa Guruge, Tax Adviser, the Ceylon German Technology and Training Institute (CGTTI), Automobile Engineering Training Institute, Orugodawatta, members of the Sub Committees on Vehicle emission control, Motor fuel quality improvement and Fiscal policies on fuels and vehicles.

I also acknowledge warmly the contribution and invaluable support extended by Mr. M.M.S.S.B. Yalegama, Deputy Project Director, Ms. H.M.L. Kamala, Project Accountants, Mr. R.M.R.D. Weerasooriya and Miss S.A.D. Manori, the first two Project Assistants and staffs of the Air Resource Management Centre (AirMAC) for their support to co-ordinate this study from the outset.

Finally I would like to place on record that the solidarity, integrity and strength of the partnership of the AirMAC team, is the success of this project.

Dr. B.M.S. Batagoda
Project Director
Urban Air Quality Management Project
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The reported data show that almost all of the diesel vehicles that did return to RMV for retesting were able to achieve the emission standards on the first try, at an average repair cost of Rs. 12,000 (US$ 138). In the case of the two-stroke three-wheelers and motorcycles, the great majority of the failing vehicles were able to be repaired on-site, and at very little cost, to achieve the emission standards. In most cases, this could be achieved by adjusting the carburetor air-fuel ratio and/or by using the correct fuel and lubricant mixture to reduce smoke emissions.

c) Fuel Quality Improvements

This component deals with programme (b) - Gasoline and Diesel Quality Improvement. The local input for the study has mainly been provided by the Ceylon Petroleum Corporation (CPC).

International Trends in Fuel Quality Specifications

The first task of the study was to provide a summary of the most important trends in fuel quality world-wide. The factors that are driving the fuel specification changes were also reviewed and discussed.

This analysis consists of:

a) The major transport fuel reformulation programmes that took place in the last 20 years
b) The rationale behind all most significant specification changes
c) The measures taken by refineries worldwide to cope with the above changes. These gave some very important directions regarding the best course of action to be followed in Sri Lanka, taking into account the structure of the local refinery (topping-reforming), and the local product slate, product demand and product quality.

In terms of product quality, the following fuel specifications should be tightened to move towards "modern" transport fuels, which are viable in the short to medium range:

Gasoline:
- top priority: lead content (already implemented in 2002), benzene
- other priorities: aromatics, front-end-volatility (RVP)
- for the time being, less attention should be paid to the sulphur and the olefins contents because they are already quite low (as in most typical topping-reforming refineries).

Diesel fuels:
- top priority: sulphur content
- other priorities: back-end-volatility (T95) and density
- for the time being, less attention should be paid to the cetane number, which is already quite high, and the aromatics content, which is already low, as the diesel fuel is mainly blended with straight-run gasoil.

However, while assessing the various case studies, all these fuel parameters shall be monitored to ensure that they would continue to be within acceptable limits, and their values shall be calculated for each case study.

Based on these fuel reformulation priorities, the following considerations could be made regarding refinery modifications and investments, for the Sapugaskanda refinery:

a) As fuel quality requirements become tighter, it is increasingly difficult for small, simple topping- reforming refineries to meet the new fuel specifications, because of the economies of scale involved in investing in additional expensive process units. In fact currently the only option for the Sapugaskanda refinery, in the face of lead elimination, is to blend gasoline with straight-run naphtha and reformate, the latter providing the bulk of the octane required.
b) The consequence of this would be gasolines with increasing amounts of aromatics. For these refineries, limiting benzene and aromatics to low levels, rules out the present approach of relying only on reformate to compensate for the octane shortfall consequent to the lead elimination. Other sources of octane such as cat-crackers, isomerates and oxygenates must be considered.
c) Considering the relative market demands for gasoline and diesel fuel in Sri Lanka, the two most serious contenders for controlling aromatics and benzene in the Sri Lankan refinery appear to be a new isomerization unit or/and the purchase of high octane oxygenates, which do not give undesirable side effects in gasoline blends; two such oxygenates are MTBE and Ethanol. The selection of either of the two is clearly depending on local economics.
d) The cat-cracker does not look attractive for Sri Lanka as this process is particularly suitable for maximising naphtha production. This does not appear to be a pressing need for Sri Lanka, where local gasoline production is practically in line with market demand, while there is a large distillate shortfall. For this reason a process aiming at the conversion of fuel oil to mainly distillate is considered in this study. One obvious candidate for this purpose, now very popular world-wide, is the hydro-cracker, that has the big benefit of providing large flexibility in meeting severe diesel fuel specifications (at the level of EURO II/III), without imposing costly limitations on the refinery crude slate. Furthermore a hydro-cracker unit would not require making dramatically more severe the current operating conditions of the hydro-fining/hydro-treating plants of the Sapugaskanda refinery.

Proposed Improved Future Transport Fuel Quality

Taking into account air quality considerations, the structure of the refining industry in Sri Lanka and the current trends in the neighboring countries, it is proposed to tighten the transport fuel specifications as shown in the following table.

Table 1: Proposed Transport Fuel Quality - Study Targets

	Gasoline 2005	Gasoline 2010	Gasoline 2015	Gasoline WWFC-Cat.2
RON (gasoline pool), min	90 (*)	90 (*)	90 (*)	91
Lead, g/l max	0.013	0.008	0.005	below detection
Benzene, vol. %	4.0	3.0	2.0	2.5
Aromatics, vol. %	45	45	40	40
RVP, kPa	60	60	60	60
	Diesel Fuel 2005 (**)	**Diesel Fuel 2010**	**Diesel Fuel 2015**	**Diesel fuel WWFC-Cat.2**
Sulphur, wt. ppm, max	3000	1000	500	300
T95, deg.C, max	380	380	365	355
Density, kg/m3, max	860	860	850	820-850
Cetane index, min	46	46	50	50***
Cetane number, min				53***
Poly-aromatics, % m/m	12	12	5	5

(*) The study assumed that the 95 RON unleaded grade will continue to be imported

(**) The study assumed that a Super Diesel grade will continue to be imported

(***) Compliance with either cetane index or cetane number is allowed.

The diesel fuel qualities proposed for 2015 are broadly consistent with those postulated by EURO II/III and by the World-wide Fuel Charter - Diesel Category 2. This study shows that, mainly because of the large diesel fuel demand in Sri Lanka, meeting these diesel fuel qualities will require large investments.

Refining Investments - Case Studies

Gasoline Reformulation

Because of relatively low gasoline demand, the total costs of lead elimination and octane upgrading are fairly low. In fact the gap of three RON units, between the current refinery capability (87 RON) and the target of 90 RON can be easily filled by the following approaches:

- short range: The base case is capable of meeting the gasoline specifications proposed for 2005 and 2010, albeit at a production level lower than today' s market demand.
- long range: build an isomerization plant, which would have the advantages of reducing dependency on imports and increase the refinery flexibility to continue to meet future gasoline demands at the proposed quality levels, not only regarding the octane quality, but also the benzene, aromatics and volatility characteristics (including the RVP, that, considering the climatic conditions in Sri Lanka, was kept, in the study, consistently at or below 60 kPa). Because of the relatively small gasoline market demand in Sri Lanka, the size of the isomerization plant assumed for this study (100,000 t/y) is smaller than the typical plants of other

refineries, including those of other Asian countries. This means that the unit cost of production of the isomerate in Sri Lanka would be higher. In the absence of isomerization, only the addition of MTBE enables compliance with the 2015 fuel specifications.

The costs of using these new blending components and investing in a new isomerization plant are:

- short range: None if the base case is selected. Incremental costs of up to Rs 0.6 per litre of 90 RON unleaded are encountered if MTBE, 95 RON unleaded and/or MMT are used.
- long range: a capital investment of about US $16.5 M would be required for the isomerization plant, but the variable operating cost relative to the use of high octane blending components would be significantly reduced, as a large octane boost derives from having upgraded some of the naphtha to isomerate. Installing an isomerization unit to meet the gasoline specifications for 2015 incurs an additional cost of Rs 0.35 per litre of 90 RON unleaded gasoline.

This product cost data must be interpreted in the light of the methodology used for their calculation (see page 59 for details). They must be assessed with caution, especially in a market, like the Asian one, where there is a surplus of product (particularly diesel fuel and refining capacity). **This surplus situation is expected to persist in the region for quite some time. This buyers' market condition is important to be kept in mind when making decisions about further investments in the refinery sector.**

Diesel Fuel Reformulation

The diesel fuel presents a bigger challenge for two reasons:

- the market demand is unusually high, and clearly out of reach of the current refinery capacity. For this reason this study examined the main case of improving diesel fuel quality at constant current refining capacitym (assuming to meet demand through imports), and also a sensitivity case where it is assumed to double the capacity (see Appendix 6 for more details).
- the present sulphur content of the diesel fuel is high and needs important reductions

A large number of cases were considered in the study. The following five approaches represent a good summary of the case studies:

A) de-bottlenecking and expansion of current Low Pressure (LP) distillate hydro-treating unit. Current refining capacity.
B) as point A) plus the use of more low sulphur crude in the refinery crude slate. Current refining capacity.
C) as point A) plus a hydro-cracker unit. Current refining capacity.

Sensitivity Cases:

D) as point C) i.e. with a hydro-cracker unit, but with a double refining capacity.
E) double refining capacity, but with the assumption of investing in a High Pressure (HP) hydro-treating unit instead of the hydro-cracker.

Table 2: Results of the sensitivity Study of Diesel Fuel Reformulation

	Approach A)	Approach B)	Approach C)	Approach D)	Approach E)
Costs - 2002 US$ million:					
Capital Investments	22.8	22.8	283.8	545.3	322.6
Annual operating costs:					
- due to the new units	0.15	0.15	1.9	3.63	2.15
- due to blending components, low S crude, imports/exports	4.46	5.86	40.87	120.4	74.1
Additional Product cost, Rs/lt:					
- gasoline	0.20	0.20	n.a.	n.a.	n.a.
- diesel fuel	0.26	0.31	n.a.	n.a.	n.a.
-overall transportation fuels	n.a.	n.a.	2.13	3.87	2.28

n.a.- non applicable

To double the refining capacity and build new modern refinery units (either hydro-crackers or HP hydro-treaters) requires very significant capital investments, which in the current bias market conditions of the Asian market should be considered with caution.

In fact, the same comments made about the investment costs for the gasoline units, apply also for diesel fuels.

Each of the above approaches would improve the diesel fuel quality quite significantly. The sulphur and cetane quality levels are summarised in the next table:

Table 3: Sulphur and Cetane Quality Levels of Diesel Fuel

	Approach A)	Approach B)	Approach C)	Approach D)	Approach E)
Sulphur content, vol. ppm	3,900	2,625	413	383	301
Cetane index	48.0	45.0	54.3	53.7	49.6

Approach A) will satisfy the specifications foreseen for Sri Lanka in 2003, but it will fall short of meeting the specifications proposed in this study for 2005. These quality targets would be met by Approach B) regarding the sulphur content, but the cetane index value would be borderline, as the low sulphur crude used to reduce the sulphur content gives a low cetane quality.

The hydro-cracker Approach C) (and also D) meet all proposed specifications up to 2015. The specification proposed for 2015 could be met earlier through imports of low sulphur diesel fuel. Approach E) clearly meets the 2005 and 2010 proposed quality targets, but is borderline regarding the 2015 proposed specifications. However the investment required by this approach is almost half of that required by Approach D).

Impact of Fuel Quality on Exhaust Emissions

A study was made of the effect that changing the fuel quality has on the emissions of the Sri Lankan vehicle fleet. This study was made using an emission inventory model, and it shows the following emission reductions for the gasoline and diesel fuel qualities of the levels proposed in Table 9.1 above.

Gasoline Reformulation:

- CO emissions from gasoline engines are largely affected by the use of oxygenated compounds as blending components. Therefore the cases involving the use of MTBE as a blending component would have the benefit of a 7% to13% emission reduction of CO. If imported 95 RON gasoline is used as a high octane blending component, the CO emissions remain practically unchanged.
- HC emissions follow the same trend of the CO emissions, albeit at a slightly lower percent level of emission reduction.
- Benzene emissions are those that are mostly affected by the above gasoline reformulation cases. The model predicted reductions in the range of 30%, when MTBE and/or isomerate are used as blending components.

The proposed gasoline reformulations have practically no impact on NOx emissions.

It is important to note that for all pollutants (including benzene which is the one mostly affected by gasoline quality changes) gasoline reformulation alone, without being complemented by the use of advanced vehicle emission control technologies, is not sufficient to compensate for the emission increases that took place in Sri Lanka in the last fifteen to twenty years, due to the vehicle population growth. Only the deployment of catalysts on new gasoline engine vehicles entering the Sri Lankan market and the control of emissions from motor cycles and tri-cycles can reverse this trend. With the move to unleaded gasoline in 2002, and because of the inherent low sulphur content of the gasoline manufactured in Sri Lanka, the catalysts would operate very effectively.

Diesel Fuel Reformulation:

- reformulated diesel fuel are chiefly affecting the emissions of NOx, PM10 and SOx.
- diesel fuels meeting the proposed 2005 specifications would reduce PM10 emissions by about 10% and SOx emissions by 70%, while their effect on NOx emissions would be negligible.
- the fuels satisfying the proposed 2010 specifications would reduce NOx emissions by about 2%, PM10 emissions by over 15% and SOx emissions by about 85%.

- finally, the diesel fuel meeting the proposed 2015 limits would reduce NOx emissions by about 4%, PM10 emissions by 20 to 25% and SOx emissions by about 95%.

It is worth noting that:
- NOx emissions are only marginally affected by fuel reformulation.
- SOx emissions depend only on the fuel composition; hence they are greatly affected by fuel reformulation (through the fuel sulphur content).
- substantial PM10 reductions seem to be possible through diesel fuel reformulation. However it is important to note that, because of the lack of published experimental data with diesel fuels of the quality marketed in Sri Lanka, the above estimates have been made through the use of US and European data and a set of assumptions about the Sri Lankan vehicles, which have not been fully tested by experimental programmes. Therefore these PM10 emission values contain potentially large uncertanties and must be interpreted with caution.

Also in this case, fuel reformulation alone, without being complemented by the use of advanced vehicle emission control technologies, is not sufficient to compensate for the emission increases that took place in Sri Lanka in the last 15 to 20 years due to the vehicle population growth. Only the deployment of vehicle emission control technologies such as EURO II and/or EURO III can revert this emission growing trend. A case study, which assumed the adoption of EURO II vehicle and diesel fuel technologies on new vehicle registrations from 2005, showed possible NOx and PM10 emission reductions up to 65% and 50% respectively by 2015.

However, it must be remembered that these advanced diesel engine technologies require lower sulphur fuels, and therefore would be satisfied by the quality of the reformulated diesel fuels of Approaches C), D), E), which require significant investments and/or imports of low sulphur diesel fuel. In the shorter range, while the refinery makes the necessary investments to reduce the sulphur content of the distillate manufactured locally, the new diesel vehicle technologies could be satisfied through the use of the imported Super Diesel.

Refining Investments - Recommendations for improving the refinery flexibility

After careful review of all the information developed on refinery investments, fuel quality improvements and their impact on emissions, the following is recommended for upgrading the refinery and improving its flexibility in satisfying tighter gasoline and diesel fuel specifications:

Unleaded Gasoline:

- short range (up to 2005): use currently available refinery blending components, and import enough 90 RON gasoline to meet local market demand.
- longer range (2010--2015): invest in an isomerization plant to:
- upgrade the light virgin naphtha from about 67/69 RON to 83 RON
- reduce/avoid dependency on imports of expensive MTBE

- increase flexibility in meeting RON, Benzene/Aromatics specifications

Diesel fuels:

- short range (up to 2005): maximise utilization of existing hydro-treating capacity and use more low sulphur crude aiming at achieving at least sulphur levels of 2,500 to 3,000 ppm
- longer range (2010--2015): invest in a hydro-cracker to:
  a) produce more distillate and move the refinery production closer to market demand, and
  b) give the refinery the necessary flexibility for meeting lower sulphur and other future diesel fuel specifications (with this investment, fuel qualities like those postulated by EURO II/III and/or World-wide Fuel Charter - Diesel Category 2 will become feasible)

However, it is important to note that a hydro-cracker plant will also increase significantly the production of gasoline blending components. Therefore, with this plant, gasoline or naphtha exports will rise significantly.

d) Fiscal Policies on Fuels and Vehicles

The Purpose of the Component

The purpose of the fiscal policies assignment is to examine the effects of alternative options for pricing diesel, petrol and kerosene and for levying duties on different fuels and vehicles. The effects of the alternative policies on long-term fiscal sustainability, households' expenditure and welfare, vehicle emissions and the environment are assessed.

Methodology

To assess the welfare effects of changes in taxes 1994 Input Output Table and data from the 1995/96 Household Budget Survey for Sri Lanka were updated and used. We assessed the extent of pollution created by vehicles from the consultants' reports and estimates of local air quality. The health costs were estimated by transferring values from studies on similar cities conducted by the World Bank, and by directly estimating the mortality impacts and costs from the levels of particulate matter. The revenue impacts of fuel price changes and the revenue-neutral levels of rebalanced fuel prices were determined from estimates of fuel consumption in 2002, international fuel prices, and assumptions about the elasticities of fuel demand. The estimate of fuel consumption for the year 2002 was computed assuming the average annual growth rate of fuel consumption for the period 1996-2001 would apply.

Prices of Transport Fuels

At the beginning of 2002 the Government of Sri Lanka made some major policy changes to the pricing of oil products. It replaced the old system of fixing the final prices of fuels independently of import prices by introducing a formula for fixing product prices that is based on world prices and it proposes to change prices monthly. In the past there have been lags of variable duration between changes in world oil prices and the changes in oil product prices made by the Government of Sri Lanka. These lags destabilised government revenue. The government has replaced *ad valorem* duties with fixed excise duties, a change that will further stabilise government tax revenue. In the past government revenue from taxes on oil products fluctuated with the price of oil, but under the new system they should be largely independent of the world oil price.

A distinctive feature of fuel prices in Sri Lanka is that the price of petrol is about twice the prices of diesel and kerosene. Although the Government of Sri Lanka has recently reduced the differential between the prices of petrol and diesel, the retail price of petrol in March 2002 was 49 Rs. per litre, compared to 26 Rs. for diesel and 17.4 Rs. for kerosene. In effect, the tax on petrol has been much higher than the taxes on diesel and kerosene. One reason for the differential tax rates is that diesel is used for trains and buses and by industrial users. Higher taxes on diesel would raise the costs of transport and prices of exports and, together with higher taxes on kerosene, would hit low-income groups. Such differential taxes are a *prima facie* source of inefficiency because they distort decisions made by consumers. They create an artificial incentive to acquire diesel-powered vehicles in place of vehicles that use petrol. The present structure of taxes on petrol, diesel and kerosene does not reflect the cost of environmental externalities, which are higher for diesel and kerosene than for petrol.

Fuel Prices and Taxation

An analysis of Sri Lankan fuel prices and taxes in March 2002 shows that:

- compared to the alternative position of importing refined products at world prices, the CPC refinery was making a loss at an annual rate of at least Rs. 1.8 billion
- the explicit annual tax revenue from oil products was Rs.20.1 billion. After deducting the revenue which would be raised if expenditure on fuel were used for other purposes, the pure fuel tax element was Rs.19.8 billion and, when the loss made by the refinery, which is in the public sector, is deducted, the budgetary contribution of the fuel taxes was Rs. 18 billion
- since 1996 there has been a substantial fall in the level of taxes on petrol measured in real terms and a slight erosion of the real tax take per litre of diesel.

Vehicle Taxes and Rules for Imports

Sri Lankan vehicle taxes are concentrated at the point in time when vehicles are imported. Vehicle import taxes are substantial and can double the cost of vehicles.

Excise duties on imported diesel cars and diesel-powered dual-purpose vehicles are much higher than for petrol versions of the same vehicles. The effective rate of excise duty on imports of petrol-powered cars and vans, 57%, compares with 111% for diesel-powered cars and vans. Again, different rates of taxation on close substitutes will distort consumers' decisions, but the difference in vehicle taxes is in the opposite direction to the difference in fuel taxes and, in part at least, it offsets the effects of the higher petrol tax on consumer decisions.

In addition there are strict rules on the age of second-hand vehicles which can be imported into Sri Lanka. Cars can be up to three years old when imported and dual purpose vehicles up to five years old. These rules affect the choice of vehicles because the price of vehicles falls with their age and so imported vans can be considerably cheaper than cars. (It is assumed that total mileage driven is related to the age of vehicles).

The Effects of Fuel Taxes, Vehicle Taxes and Vehicle Age Import Rules

Data on fuel consumption and kilometres travelled suggest that there is little if any adulteration of diesel by kerosene at present, though this could become a problem if diesel taxes were to increase significantly relatively to those on kerosene.

The share of petrol in the fuel used for transport has fallen from 30% in 1990 to 18% in 2002. Although the tax on diesel is lower, this has not led to the substitution of diesel for petrol cars. The proportion of diesel-powered cars imported has fluctuated, probably in response to the introduction and withdrawal of import duty concessions, but the proportion has remained small, at around 10% of the total stock of cars in use. However, there has been a rapid expansion of dual-purpose, light duty vehicles using diesel. Whereas car ownership has been growing at 5-6% p.a., and heavy trucks at about 6%, in line with real GDP growth, that of vans and dual purpose vehicles has been growing at 8-9%, and of all vans plus cars at 7%. There therefore appears to have been some substitution of cars by these vehicles.

A series of analyses were made to compare the break-even points for sizes and types of cars and vans in terms of kilometres per year using three sets of assumptions:

- current prices and taxes on fuels and vehicles
- current prices without any taxes on fuels and vehicles
- current prices with a pollution tax on diesel but with no other taxes.

The comparisons indicate whether current taxes are promoting efficient choices of vehicles. We find that the existing taxes are *not* distorting the choice of fuel-type for cars. The incentive to buy diesel-powered cars created by the lower tax on diesel is offset by higher vehicle taxes on diesel cars. However, at least in some cases, the existing fuel and vehicle taxes encourage diesel dual-purpose vehicles (vans) when petrol choices would be efficient. In addition we find that the current lower age limit on imported second-hand cars than vans encourages the substitution of diesel-powered vans for petrol cars. As the import duties are *ad valorem*, cheaper vehicles,

particularly vans and dual purpose vehicles, are unduly encouraged, despite the higher rates of import duty on diesel vehicles. In the absence of taxes, or with equal fuel taxes with or without an extra pollution tax, petrol vans would be cheaper as well as efficient. Unless the import age restrictions are changed, though, vans may still be inefficiently substituted for cars.

Vehicle Emissions and Pollution Costs

The costs of PM pollution in Colombo, the most serious source of vehicle pollution, are estimated to be about $5/kg or 3.2 Rs/litre of diesel when other pollutant costs are included. Around 80% of the vehicular PM emissions come from diesel engines. Heavy trucks and buses are the main source of these pollutants, probably accounting for half the total. There are sound economic and technical reasons for these large vehicles to use diesel and there is no case for switching these to petrol vehicles. However, older vintages of vehicles have much higher rates of pollution and so reductions in the age of vehicles can have substantial effects on pollution. There may be scope for reducing this pollution by administrative action and enforcing a regime of vehicle testing. Fiscal policy can be effective in dealing with the other main source of these pollutants. About one-sixth of the diesel PM emissions are from pick-ups and dual-purpose vehicles. Vehicle import restrictions and fuel taxes have favoured imports of diesel dual-purpose vehicles. If this fiscal bias were reversed, pollution would, in time, be reduced.

Probably less than 20% of PM emissions come from petrol engines. Here the major contributor is motor cycles and three-wheelers with two-stroke engines. However, the data on motor cycle emissions is unreliable and new data is required before final decisions are taken. Our recommendations are based on the data available to us and illustrate the methodology for assessing the social costs of using two-stroke cycles. A drastic remedy would be to phase out two-stroke engines by banning their import. We find, however, that this would not be justified on our best estimate of the cost of pollution damage they cause. The replacement of existing two-stroke engines could be somewhat encouraged by a higher registration fee for two-stroke vehicles than on four-stroke vehicles, or an annual levy on two-stroke vehicles. The defensible level for the differential registration fee would probably not encourage many buyers to purchase four-stroke rather than two-stroke vehicles unless the prices of four-stroke engines fell considerably. In any case, the benefits of policies to reduce pollution from motor cycles are likely to be limited in the short run because the main source of pollution is the existing stock of older bikes.

Policy Options

Our results are sensitive to the accuracy of the data and assumptions we have used. In particular, the choice of vehicles (the break-even analyses) depend on the import prices of comparable alternative choices, maintenance costs, and the remaining life, and whether, as we assume, the remaining life depends solely on distance driven.

A sensitivity analysis of changes to duties on diesel and petrol shows that revenue neutral changes to equalise the rates of duty would correct the choice of fuel for vehicles, though not necessarily the choice of type of vehicle without further adjustments to import or registration taxes. Various changes to duties and annual license fees are analysed. These may be necessary if petrol continues to be more heavily taxed than diesel.

For illustrative purposes, we have projected the effect that discouraging all imports of all diesel-fuelled cars and dual purpose vehicles/light vans would have on particulate (PM) emissions. Compared to a projection of business as usual for the total emissions from trucks, light vans and diesel cars (that in 2000 accounted for over 60% of total PM emissions from vehicles, the rest being from buses, land and two-stroke vehicles), ending imports would substantially reduce PM emissions from these sources. This is the maximum that may be achieved, based on the (*unreasonable*) assumption that there is no change in emissions per diesel vehicle over the next 20 years, and that *all* imports of diesel vans would be prohibited or otherwise discouraged. Some types of high mileage *commercial* vans (unsuitable as substitutes for private cars) are likely to remain the efficient choice. This case was not analysed as the data provided to us suggests that most vans in Sri Lanka are dual-purpose.

The Impact of Policies on Households' Welfare

Household expenditure survey and input-output data for Sri Lanka are used to assess the welfare effects of changing fiscal policies. The share of expenditure on fuel is a rather small percentage of total expenditure, averaging 5% for the top decile and 3.5% for all households. These percentages include the direct consumption of fuels *and* the indirect consumption via purchases of other goods and services. The welfare effects of changing duties are, therefore, modest.

Policies that include an increase in the duty on kerosene have a stronger effect on the lower income deciles than do policies that focus on petrol and diesel duties. Taxes on petrol are progressive, those on diesel relatively neutral.

Recommendations

When determining the appropriate level of duty to levy on diesel, the component representing road user costs needs to be more accurately measured than the rough estimates provided in this report. We therefore recommend that a road user charging study be undertaken to assess the charge that can be justified for diesel fuel in order to charge appropriately for road user costs. We have also had to make rather rough estimates of pollution costs and recommend that these estimates be refined in the light of better air pollution and emissions data that should become available as the quality of monitoring improves.

Over time, policies to transfer demand for diesel dual-purpose vehicles and cars to petrol vehicles would result in a significant reduction in pollution. The analysis

showed that the current fuel tax/price policies do not have a significant effect on the choice between diesel and petrol cars, but they do encourage the inefficient choice of diesel for dual-purpose vehicles. Vehicle import policies such as age limits for different types of vehicles and high *ad valorem* taxes duties play by far a larger role, and need examination to see whether they need reform to improve consumer choice and environmental impacts. Banning the import of certain vehicles may seem an appealing policy to address particular environmental problems, such as pollution caused by diesel-powered vehicles. However, these policies should be also applied with caution and on the basis of a clear understanding of environmental gains and economic costs.

We have considered the effect of banning all two-stroke motor cycles. Although a ban would reduce the PM emissions from petrol vehicles and these possibly account for as much as 20% of the total PM emissions, we consider that such a ban is *not* warranted given our best estimates of the emissions of two-stoke cycles and the health damage costs. (We note that these estimates of emissions are very unreliable).

A potential source of instability for government revenue is the effect of inflation to reduce real revenue from fixed excise duties. The remedies are to index-link fixed excise duties and maintain constant *ad valorem* rates, perhaps revising these when the price of the tax base deviates from other costs, as it might for imported fuels.

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ABBREVIATIONS AND ACRONYMS

API	American Petroleum Institute
AQIRP	Air Quality Improvement Research Programme
CCR	Conradson Carbon Residue
CDU	Crude Distillation Unit
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO2	Carbon Dioxide
CPC	Ceylon Petroleum Corporation
E150C	% evaporated at 150 degrees centigrades
EPEFE	European Programme on Emissions, Fuels and Engine technologies
ETBE	Ethyl Tertiary Butyl Ether
FBP	Final Boiling Point
FCC	Fluid Catalytic Cracking
g/l	grams per litre
gMn/lt	grams of Manganese per litre
GOSL	Government of Sri Lanka
HC	un-burnt hydrocarbons in the exhaust gas of engines
HFO	Heavy Fuel Oil
IPIECA	International Petroleum Industry Environmental Conservation Association
kg/m3	kilograms per cubic metre
kPa	kilopascals
LDV	Light duty vehicles
LEV	Low Emissions Vehicles
LPG	Liquefied Petroleum Gas
m/m%	% by mass
MMT	Methylcyclopentadienyl Manganese Tricarbonyl
MON	Motor Octane Number
MTBE	Methyl Tertiary Butyl Ether
NAAQS	National Ambient Air Quality Standards
NOx	Nitrogen oxides
O2	Oxygen
PM	Particulate Matter
PM10	Particulate Matter with size below 10 microms
ppm	parts per million
psi	pounds per square inch
RFG	Re-Formulated Gasoline
RON	Research Octane Number
Rs./lt	Rupies per litre
RVP	Reid Vapour Pressure
SO2	Sulphur dioxide
t/cd	tonnes per calendar day
t/y	tonnes per year
T50	Temperature at which 50% of the fuel evaporates
T90	Temperature at which 90% of the fuel evaporates

T95	Temperature at which 95% of the fuel evaporates
TAME	Tertiary Amyl Methyl Ether
TSP	Total suspended particulate matter
UL	Unleaded Gasoline
ULEV	Ultra Low Emissions Vehicles
US-EPA	U.S. Environmental Protection Agency
VB	Visbreaker
VOC	Volatile Organic Compounds
Vol%	% by volume
WHO	World Health Organization

Chapter - 1

INTRODUCTION

1.1 HISTORY OF THE PROJECT

1.1.1 Clean Air 2000 Action Plan

Recognizing growing problem of air pollution in the Colombo Metropolitan Area the Government of Sri Lanka (GOSL) through the World Bank funded Metropolitan Environment Improvement Programme (MEIP) developed and published the Clean Air 2000 Action Plan (CA2AP) for air quality management in February 1993. The CA2AP combines the policy and strategic measures that need to be introduced to the overall policy making framework. Besides approving the Action Plan, the Cabinet of Ministers also appointed an Implementation Committee chaired by the Secretary to the Ministry in charge of the Subject of Environment and directed that the Action Plan be the framework for future international assistance in the area of air quality management.

This policy supports the many initiatives being currently undertaken by different sectors and advocates the following principles as an integrated approach to air pollution abatement.

- Vehicle Inspection and Maintenance
- Fuel reformulation, pricing and fleet mix
- Emission Inventory, monitoring and reduction
- Standard Setting
- Institutional framework and regulatory compliance
- Economic Instruments
- Transport Planning and Traffic Management

The CA2AP also assigns implementing priorities including institutional responsibilities.

1.1.2 Vehicle Emissions as major contributor

Rapid urbanization and growth in transport demand together with inadequate public transport and rapid motorization are some common issues in many developing countries and Sri Lanka is no exception. The rapid increase in the vehicle fleet is mainly due to importation of used vehicles. The growing vehicle population together with the high emission rates from many of these vehicles has been associated with serious air pollution problems in many urban areas. In particular, vehicular emissions are linked to a number of health effects, including respiratory and cardiovascular diseases such as asthma and lung cancer.

Emissions from vehicles consist of a large number of pollutants resulting from a number of different processes. The most critical source of pollution is vehicular exhaust that is generated during the fossil fuel combustion process and subsequently emitted from the tailpipes. Primary pollutants in the vehicular exhaust that can produce health effects include carbon monoxide, hydrocarbons, nitrogen oxides, sulphur dioxide and other toxic substances such as particulate matter and lead. Additionally, other gases (such as ozone) and particles (sulphate and nitrates) can form in the atmosphere as secondary pollutants from reactions involving some of those primary emissions.

Emission from on-road motor vehicles is one of the main air pollutant sources in Sri Lanka, particularly in urban sector. Ever increasing use of vehicles in transport sector

without proper monitoring, controlling and regulation of emissions together with lack of standards and the national interest has resulted in deterioration in air quality in main cities, especially in Colombo. This has caused adverse health conditions and poor quality of life. The estimation of these emissions is important from a number of viewpoints. Firstly, development of local emission inventories is essential to draw up a national action plan and also to carryout research and development activities in mitigating vehicle emission. Secondly, these inventories are very useful in comparing the present status with the ambient air quality standards or even developing new standards. Further, on-road motor vehicle emission estimates could be used to determine if area-based transportation plans and projects are consistent with the national implementation plan. Due to the dynamic nature of the phenomenon arising from the changes in fuels & combustion technologies, mix and the quantity of the vehicle fleet, etc., such inventories should be continuously upgraded.

Therefore, reduction and control of vehicular emissions require comprehensive strategy, which requires emissions standards for new vehicles, cleaner fuels, emissions standards and inspection & maintenance program for in-use vehicles, vehicle importation policies, traffic & demand management measures; and also institutional development, awareness, education and training. In this regard, the government of Sri Lanka obtained an IDF Grant from the World Bank to strengthen the institutional and policy framework for urban air quality management in Colombo. The overall objective of the project was to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions.

It is evident from the actions proposed in CA2AP to reduce air pollution have mainly been concentrated on vehicle emission reduction. Air pollution from vehicle emissions has accounted for the major portion since the inception of air pollution problem in Colombo.

Air pollution from industrial and vehicular emissions, particularly in Colombo is now becoming a matter of concern. The transport sector accounts for nearly two thirds of country's fossil fuel consumption and is the main cause of urban air pollution. There is good evidence to show that the main emissions of concern with respect to air pollution are particulate and sulfur dioxide. Rapid urbanization has placed additional demands on road transport systems. In addition, improvements to the national and city road networks have not been responsive to the increased number of road vehicles resulting in urban congestion leading to wastage of fuel and subsequent air pollution.

1.1.3 Project Approach of Urban Air Quality Management Project

The project consisted of four components.

(i) *Institutional Development*:
This component includes the support for strengthening of the current institutional and organizational capacity for air quality management through the establishment of an air quality cell (AirMAC) under the Ministry of Environment and Natural Resources.

(ii) *Vehicle emissions reduction*:
The grant was used to strengthen the capacity of the Department of Motor Traffic, the Planning Unit of the Ministry of Transport, and the Central Environmental Authority for vehicle emissions control, and to assist in revising in-use vehicle emission standards, establishing an inspection and maintenance program, limiting the number of polluting

vehicles on the road, awareness-raising, and exploring innovative partnership arrangements and financing mechanisms.

(iii) *Fuel quality improvement*:
This component was intended to facilitate policy decisions on implementing realistic, fiscally sound and socially beneficial plans for phasing out leaded gasoline, improving diesel quality and rationalizing demand for these fuels which is currently distorted by a large price differential. In particular, the grant was used to examine the feasibility of tightening gasoline and diesel quality standards; analyse fiscal, financial and public health implications of changes in fuel specifications and relative prices as well as the impact of these changes on low-income groups; and recommend possible options to the Government of Sri Lanka.

(iv) Fiscal Policies on Fuels and Vehicles:
Alternative options for pricing diesel and gasoline and levying duties on different vehicles were expected to be examined, from the point of view of long-term fiscal sustainability, impacts on households' welfare (expenditure) and decreasing most harmful vehicular emissions. While the activity addresses issues raised during discussions on components (ii) and (iii), it was proposed as a separate component because of different expertise and main counterpart agency required for its implementation.

Further, the project had allocated a grant to the Ministry of Transport in the Year 2002 budget for the Inspection of vehicles for emissions and enforcement of new air pollution regulations. Under this component of the project following main activities had been identified:

- Purchase of Equipment for testing of emissions
- Training of Staff
- Incorporation of emission testing component in the fitness test
- Carrying out random vehicle tests
- Regular monitoring purposes

Among these, it had been recognized that the third activity, together with the necessary infrastructure & institutional mechanism to complete it and other related activities, deserves special attention since emission regulations becomes mandatory from the year 2003.

The vehicle emission standards, fuel quality standards and vehicle specification standards for importation gazetted under the Gazette Extraordinary No. 1137/35 on 23rd June 2000 came into effect from 1st July 2003. In particular, the implementation of vehicle emission standards require many factors/activities to be fulfilled, including followings:

- Establishment of an institutional mechanism
- Establishment and accreditation of testing centers
- Training of technicians to use the emission monitoring equipment
- Purchase of equipment
- Implementation of pilot testing programme
- Strengthening garages for engine repair to reduce emissions
- Awareness creation among drivers, owners and general public, etc.

The above list of activities indicates the importance of collaborating with many other organizations, apart from Department of Motor Traffic, such as Ministry of Environment, Central Environment Authority, Traffic Police, Universities, Technical Colleges, etc. Further, such activities add extra works other than routine works to all these institutes.

1.2 TRANSPORTS AND ENVIRONMENT

Ever since the mankind's evolution, energy has been the prime vector of human society. Interaction of energy and human society has indented many milestones in human civilization, starting from discovery of fire, invention of the wheel, steam engine, discovery of electricity, internal combustion engine, nuclear fission and fusion, to propelling of space vehicle to conquer the space. Science and technology developments fuelled by energy have enabled to satisfy basic human needs, improving social welfare and achieving economic development. However, the development of the technology has resulted in many effects that endanger the quality of life of current and future generations and carrying capacity of ecosystems. Even though the natural forms of energy sources are inert, their extraction, conversion to more useful forms and usage always generate undesirable by-products and emissions that result in environmental problems at every scale (i.e. from the health impacts of wood smokes in rural households to the disruption of global climate by emission of greenhouse gases), irrespective of whether the source is fossil, mineral or renewable. For instance, the combustion of fossil fuels is responsible for most urban air pollution, regional acidification and risks of human induced climate change. One of such main activity is the use of fossil fuel combustion systems for transportation.

Over the past 50 years, the worlds vehicle population has grown fifteen-fold, now exceeding 700 million units and will soon reach 1 billion. Most of these vehicles were originally concentrated in the highly industrialized countries, but an increasing number of urbanized areas in developing countries and Central and Eastern Europe are now also heavily congested. While these vehicles have brought many advantages, the benefits have been at least partially offset by excess pollution which has resulted in many adverse effects. In particular, generation of vehicular exhaust during the burning of fossil fuel is one of the most critical source of pollution, which has a number of potential undesirable effects: high levels of urban air pollution; acid rain and changes in global climate. Therefore there is a great need for utilization of fuel for transport in a rationale manner with minimum environmental degradation and health hazards. The importance of these aspects has received a new momentum in the recent past with the concerns & mechanisms originated by international level activities

1.2.1 Technology Used In Transport Sector

Major transport categories include road, air, rail and ships. In general road transport and aviation are the most important sources as they account for the majority of mobile-source fuel consumption in the world. The main engine technology used in road transport sector is the reciprocating internal combustion (IC) system.

IC engines are generally classified by their fuel burned, method of ignition, combustion cycle, etc. The three primary fuels for reciprocating IC engines are gasoline, diesel fuel oil, and natural gas. Gasoline is used primarily for smaller engines. Diesel fuel oil is the most versatile fuel and is used in IC engines of all sizes. The methods of ignitions are: compression ignition (CI) and spark ignition (SI). All diesel-fueled engines are compression ignited, and all gasoline-fueled engines are spark ignited.

Combustion cycle for reciprocating IC engines may be accomplished in either four strokes or two strokes. Two-stroke engines have the advantage of higher power to weight ratio

compared to four-stroke engines when both operate at the same speed. However, combustion can be better controlled in a four-stroke engine and excess air is not needed to purge the cylinder. Therefore, four-stroke engines tend to be more efficient, and typically emit less pollutants (primarily unburned hydrocarbons) than two-stroke engines.

In the recent past, there has been substantial progress in introducing advanced technologies for emission control on new vehicles. These include fuel injection, exhaust gas re-circulation, catalyst, secondary air injection, pre-chamber or swirl-chamber concepts, etc., with conventional fossil fuels; alternative (cleaner) fuels; and also automobile technologies with alternative power packs such as electric, hybrid and fuel cells.

1.2.2 Emissions in Transport Sector

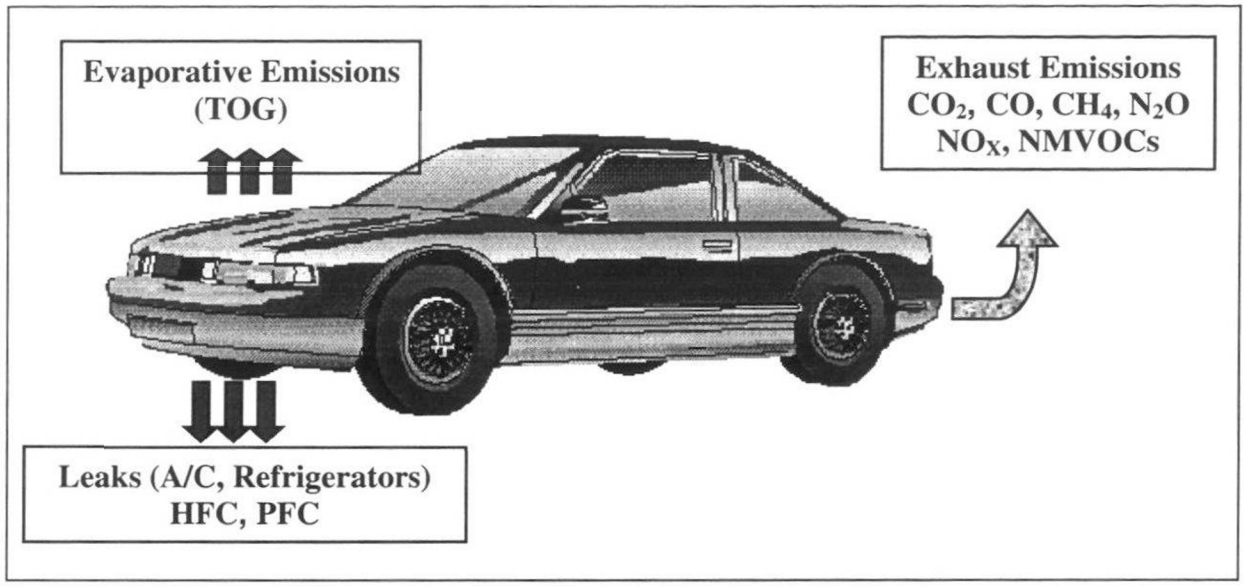


Figure 1.1: Different processes of vehicular emissions

Emissions from mobile sources consist of a large number of pollutants resulting from a number of different processes. The most commonly considered are exhaust emissions, which result from fuel combustion and are emitted from the vehicle exhaust tailpipe, and evaporative emission processes at various locations throughout the fuel delivery and storage system. Emissions of GHGs from mobile sources include CO_2, CO, CH_4, N_2O, NO_X, and NMVOCs. Evaporative emissions result in TOG (total organic gas) emissions only.

(a) *Nitrogen Oxides*

Nitrogen oxide formation occurs by two fundamentally different mechanisms: thermal NO_X and fuel NO_X. The predominant mechanism with internal combustion engines is thermal NO_X. Some NO_X, called prompt NO_X, is also formed in the early part of the flame from reaction of nitrogen intermediary species, and HC radicals in the flame. Gasoline, and most distillate oils have no chemically-bound fuel nitrogen and essentially all NO_X formed is thermal NO_X.

(b) *Total Organic Compounds*

The pollutants commonly classified as hydrocarbons are composed of a wide variety of organic compounds and are discharged into the atmosphere when some of the fuel remains

unburned or is only partially burned during the combustion process. Most unburned hydrocarbon emissions result from fuel droplets that were transported or injected into the quench layer during combustion. This is the region immediately adjacent to the combustion chamber surfaces, where heat transfer outward through the cylinder walls causes the mixture temperatures to be too low to support combustion.

Partially burned hydrocarbons can occur because of poor air and fuel homogeneity due to incomplete mixing, before or during combustion; incorrect air/fuel ratios in the cylinder during combustion due to maladjustment of the engine fuel system; excessively large fuel droplets (diesel engines); and low cylinder temperature due to excessive cooling (quenching) through the walls or early cooling of the gases by expansion of the combustion volume caused by piston motion before combustion is completed.

(c) *Carbon Monoxide*

Carbon monoxide is a colorless, odorless, relatively inert gas formed as an intermediate combustion product that appears in the exhaust when the reaction of CO to CO_2 cannot proceed to completion. This situation occurs if there is a lack of available oxygen near the hydrocarbon (fuel) molecule during combustion, if the gas temperature is too low, or if the residence time in the cylinder is too short. The oxidation rate of CO is limited by reaction kinetics and, as a consequence, can be accelerated only to a certain extent by improvements in air and fuel mixing during the combustion process.

(d) *Smoke and Particulate Matter*

White, blue, and black smoke may be emitted from IC engines. Liquid particulates appear as white smoke in the exhaust during an engine cold start, idling, or low load operation. These are formed in the quench layer adjacent to the cylinder walls, where the temperature is not high enough to ignite the fuel. They consist primarily of raw fuel with some partially burned hydrocarbons and lubricating oil. White smoke emissions are generally associated with older gasoline engines and are rarely seen in the exhaust from diesel or gas-fueled units. They cease when the engine reaches its normal operating temperature and can be minimized during low demand situations by proper idle adjustment.

Blue smoke is emitted when lubricating oil leaks, often past worn piston rings, into the combustion chamber and is partially burned. Proper maintenance is the most effective method of preventing these emissions from all types of IC engines.

The primary constituent of black smoke is agglomerated carbon particles (soot). These form in a two-step process in regions of the combustion mixture that are oxygen deficient. First the hydrocarbons decompose into acetylene and hydrogen in the high temperature regions of the cylinder. Then, when the local gas temperature drops as the piston moves down and the gases expand, the acetylene condenses and releases its hydrogen atoms. As a result, pure carbon particles are created. This mechanism of formation is associated with the low air/fuel ratio conditions that commonly exist at the core of the injected fuel spray, in the center of large individual fuel droplets, and in fuel layers along the walls. The formation of particles from this source can be reduced by designing the fuel injector to provide for an even distribution of fine fuel droplets such that they do not impinge on the cylinder walls.

Once formed, the carbon will combine with oxygen to form CO and CO_2 if it is still at an elevated temperature. Since the temperature of the exhaust system is too low for this oxidation to occur, soot exiting the combustion chamber before it has had the opportunity to oxidize completely will be discharged as visible particles.

Because soot formation is very sensitive to the need for oxygen, its discharge is greatest when the engine is operating at rich air/fuel ratios, such as at rated power and speed. Therefore, naturally aspirated engines are likely to have higher smoke levels than.turbocharged engines, which operate at leaner air/fuel ratios.

PM_{10} is the name applied to the smaller sized particles in the air (less than 10 micrometers in aerodynamic diameter). Exposure to PM_{10} can result in both short and long term reductions in lung function because the particles are too small to be trapped by the nose and large enough that some deposition in the lungs occurs. PM_{10} is the pollutant that causes most of the air-pollution-induced reduction in visibility.

(e) *Sulfur Oxides*

SO_X emissions are a function of only the sulfur content in the fuel rather than any combustion variables. In fact, during the combustion process, essentially all the sulfur in the fuel is oxidized to SO_2. The oxidation of SO_2 gives SO_3, which reacts with water to give sulfuric acid (H_2SO_4), a contributor to acid precipitation. Sulfuric acid reacts with basic substances to give sulfates, which are fine particulates that contribute to PM_{10} and visibility reduction. Sulfur oxide emissions also contribute to corrosion of the engine parts.

The vehicular emission characteristics of an urban area are very complicated due to the existence of large number of different types of vehicles in the fleet. Vehicles are usually organized into categories with common emission characteristics, based on vehicle type (two & three wheelers, car, truck, bus, etc.), fuel type (gasoline, diesel, liquefied fuels, etc.), gross vehicle weight, age and the level of emission control technology on the vehicle. Each vehicle is operated in a unique manner under various driving conditions with different speeds and loads. In addition, vehicles are subjected to varying levels of maintenance and tampering & misfueling. As a result, emissions from different motor vehicles can vary by multiple orders of magnitude.

The primary components of an vehicle emission factor model include the base emission factors, characterization of the vehicle fleet (which includes model year, the age distribution of vehicles within the class, annual mileage by vehicle age, and average speed), fuel characteristics, vehicle operating conditions and the effect of local ambient conditions, the effect of alternative Inspection & Maintenance programs and the effect of tampering and misfueling. None of these factors is static: technology is continually evolving, leading to changing in-use emission performance. Changes in fuel prices and economic conditions lead to changes in vehicle sales and travel patterns. A substantial effort is required to accurately quantify these factors and to stay contemporary with the influence of all of these factors on vehicular emission levels.

1.2.3 Vehicle Fleet in Sri Lanka

In year 2000, the estimated total active vehicle fleet is about 1,165,000, which is about 1.9 times that in 1991. However, the vehicle ownership ratio has reduced from 28:1 in 1991 to 20:1 in 2000. The per capita petrol consumption has increased from 12.7 liters to 15.9 liters and that of diesel from 28.7 liters to 54.7 liters, from 1991 to 2000. This shows that per capital diesel consumption has increased by 91% but per capital petrol consumption has increased only by 25%, indicating a sharp changes in the fleet mix. The major changes are the rapid increase of three wheelers (as well as two wheelers) and the small diesel vehicles (due to pricing policy of diesel vs petrol and vehicle importation policies). These trends have aggravated the air pollution problems in the urban sector.

The growth of total active vehicle population during last two decade is presented in the following graph.

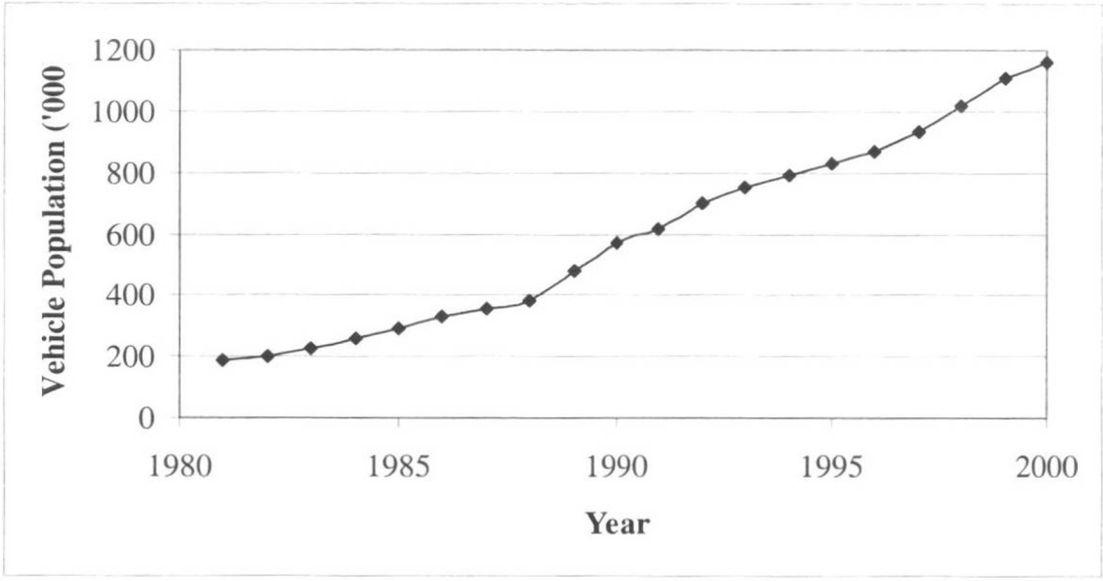


Figure 1.2: Total active vehicle population

The estimated active vehicle fleet characteristics of road transport in Sri Lanka in year 2000 is presented in the following table.

Table 1.1: Active vehicle fleet characteristics in year 2000

Vehicle Type	Fuel	No. of Vehicles	Average km/y	Fuel Economy (Urban) liters/100km
Cars and light vehicles	Gasoline	142,661	8,000	13.4
Cars and light vehicles	Diesel	18,267	15,000	9.2
Taxis	Gasoline	4,607	22,000	13.4
Pick-up & Dual purpose	Gasoline	9,418	8,000	16.6
Pick-up & Dual purpose	Diesel	110,236	21,000	12.1
Minibuses	Gasoline	1,389	30,000	16.6
Minibuses	Diesel	8,405	30,000	12.1
Medium buses	Diesel	15,717	30,000	38.1
Heavy buses	Diesel	10,311	63,000	43.8
4-wheel-drive	Diesel	12,378	10,000	12.1
Trucks	Diesel	73,341	52,000	28.6
Land Vehicles	Diesel	59,937	12,000	28.6
Motor-cycles 2-Stroke	Gasoline	375,929	5,000	4.7
Motor-cycles 4-Stroke	Gasoline	200,495	7,450	3.9
Motor-tricycles	Gasoline	120,086	12,000	5.2

In addition to the road vehicles, other modes of transport in Sri Lanka include Railways (with effective fleet of about 200 diesel locomotives and 46 power sets), Navigation (which includes international marine transport and coastal shipping & fishing boats) and Aviation (with few organizations operating the local air transport).

1.2.4 Options for Reduction of Vehicular Emission

In the recent past, there has been substantial progress in introducing advanced technologies for emission control on new vehicles. However, rapid increase in the vehicle fleet in developing countries at present is mainly due to importation of used vehicles and, as a result, older vehicles or vehicles with little or no functioning emission controls are the major source of emissions. Several strategies have been emerged over the years to control the emission from in-use older vehicles, which include Inspection & Maintenance (I/M), Retrofit, Accelerated Retirement, Import Restrictions and Alternative Fuel Conversion.

A simple, but effective I/M program can significantly reduce emissions from uncontrolled vehicles. Two speed idle test of CO and HC on gasoline vehicles and smoke opacity test on diesel vehicles can be used to identify the gross emitters and the vehicles which would most benefit from remedial maintenance. I/M programs help identify equipment defects and failures; and also discourage tampering with emission controls or misfueling. However, the inspection, enforcement and mechanisms for I/M program should be designed carefully, since weak administrative and regulatory arrangements can result in massive evasion of the program and corruption practices. Further, effective I/M program essentially requires well-trained and well-equipped vehicle repair technicians and facilities, in addition to testing centers with adequate facilities and good quality control. As vehicle technology advances, more sophisticated test procedures may be necessary, including loaded mode tests that use a dynamometer to simulate the work that an engine must perform in actual driving.

Another strategy for reduction of emission from older vehicles is to retrofit them with pollution control devices, such as catalytic converters. Past experiences in some countries indicate that retrofit program can be very successful, if they are focused on specific vehicle categories with dedicated, controlled and well-maintained fleets. Care should be taken in evaluating the costs and benefits of such a program. Further, it also requires supply of good quality fuel, durable and efficient equipments and adequate installation facilities. Note that fuel quality improvement is an essential element in a vehicular emission reduction program. In addition to catalytic converters, there are many other 'emission control devices (and fuel additives)' in the market. Performances of these devices and additives under real driving conditions are not known or proven; the actual effect would definitely vary from vehicle to vehicle and general conclusion on the performance cannot be derived.

Vehicular emission reduction program could be supplemented by accelerated retirement (scrappage) scheme, which is designed to take older, high-polluting vehicles off the road. Such a program can also result in additional benefits such as fuel saving and improved fleet safety. However, this could lead to increase in demand and prices of remaining vehicles in the fleet, which adversely affects lower income vehicle buyers. Another option for reducing vehicular emission is alternative (cleaner) fuel conversion, which includes compressed natural gas (CNG), compressed liquefied petroleum gas (LPG), methanol (made from natural gas, coal or biomass), ethanol (made from grain or sugar), vegetable oils, hydrogen, electricity, synthetic liquid fuels, and various fuel blends such as bio-diesel (which is produced by reacting vegetable or animal fats with methanol or ethanol).

As stated previously, importation of used vehicles (and used engines and other parts) is a very serious problem in many developing countries. One should note that there are no restrictions by countries exporting used vehicles or engines, as such exportation is very much beneficial to them, and many developing countries become junk yards of used

vehicles. Therefore restrictions or banning through appropriate fiscal or tax policies and more stringent emission standards for importation are successful approaches for vehicular emission reduction. However, exact mechanism of importation restrictions should be developed by considering the environmental and health hazards against the social benefits of used vehicles.

Finally, successful implementation of vehicular emission reduction program requires participation and support from all stakeholders including vehicle owners, general public and the media, in addition to the capacity enhancement and mobilization of the present institutions.

Chapter - 2

INSTITUTIONAL DEVELOPMENT

2.1 AIR RESOURCE MANAGEMENT CENTER (AirMAC)

Management of air resources needs an integrated effort by several institutions and agencies for many diverse activities such as problem assessment, identification of sources of pollutions, modeling of pollutions, development of emission inventory, formulation of policies and implementation, enforcement, monitoring & control, awareness and training, development of infrastructure, etc. In this regard, the Air Resource Management Center (AirMAC) was established under the financial support from IDF grant.

The Air Resource Management Center (AirMAC) was established jointly by the Environmental Economics and Global Affairs Division of the Ministry of Environment & Natural Resources and Central Environmental Authority in partnership with all stakeholders of air resource. The key partners of the AirMAC include Ministry of Environment & Natural Resources, Ministry of Finance and Planning, Ministry of Transport, Highways & Civil Aviation, Central Environmental Authority, Colombo Municipal Council, Ceylon Petroleum Corporation, Department of Motor Traffic, Traffic Police, Industrial Technological Institute, National Building Research Organization, Meteorological Department, Atomic Energy Authority, National Engineering Research and Development Centre, National Science Foundation, Universities, Sri Lanka Automobile Association, Chambers of Commerce and Industries

Vision of AirMAC

"Clean Air: Healthy Nation" is the vision of AirMAC.

Mission of AirMAC

Mission of the AirMAc is to provide leadership, guidance and facilitation to manage our air resource by mitigating the air pollution in order to enhance the health and well being of public and the quality of our environment.

Thrust Areas of AirMAC

Thrust areas identified for the AirMAC to operate include:

- Policy Development
- Planning and Programming
- Awareness Creation/ Public Sensitization
- Legal & Institutional Development
- Review/ Set Standards

- Inter Agency Coordination
- Air Quality Monitoring
- Collection & Dissemination of Air Quality Data/ Information
- Vehicular Emission Controlling
- Emission monitoring and modeling
- Capacity building and training
- Research/ Studies

Objectives of AirMAC

Objectives of AirMAC include:

- Development and smooth function of an effective coordination mechanism
- Integration of air pollution abatement programms implemented in the island
- Development & implementing public sensitization programmes
- Institutional strengthening, training, capacity building of related staff of air resources management
- Development of policies and programme
- Harnessing of resource for air resource management
- Establishment of air resource information Network for collection and dissemination of air quality documents
- Promotion & facilitation of air quality research with a view to ensuring of clean and safe air for the health and well being of the people.

2.2: LEGAL FRAMEWORK FOR THE IMPLEMENTATION OF VEHICLE EMISSION STANDARDS IN SRI LANKA

2.2.1 Introduction

This Section explores the possibilities of implementing the vehicle emission standards in Sri Lanka by reviewing the legal provisions under the National Environmental Act and the Motor Traffic Act. It also explores the possibility of implementing vehicle emission standards in a province or in a local government authority as a pilot project without implementing them throughout the nation. Another aspect that is reviewed under this Section are the constitutional provisions on the devolution of power. Under this part, the possibilities have been explored whether vehicle emission standards in only a particular province could be achieved under a national regulatory framework.

This opinion surveys the constitution of the Democratic Socialist Republic of Sri Lanka and its amendments with particular reference to the thirteenth amendments. It analyses the relevant provisions in the National Environmental Act and amendments, together with the regulations, the Motor Traffic Act and amendments and the provincial statutes that deal with the environment.

2.2.2 National Environmental Act

This act provides for, among other things, the making of provision for the protection and management and enhancement of the environment, and for the prevention, abatement and control of pollution.

The Central Environment Authority (CEA) has been established under the provision in part I of this act. The powers, functions and the duties of the Authority are given in part II of the act. Among these are,

1. The administration of provisions of the act and regulations made under it. {Section 10 (a)}.
2. To specify standards, norms and criteria for the protection of beneficial uses and for maintaining the quality of the environment. {Section 10 (e)}.
3. To be responsible for the co-ordination of all regulatory activities relating to the discharge of waste and protection and the improvement of the quality of the environment. {Section 10 (f)}.
4. To regulate, maintain and control the volume, types, constituents and effects of waste, discharge, emissions, deposits or other sources and sub sources of pollution, which are of danger or potential danger to the quality of the environment or any segment of the environment. {Section 10 (g)}.

The part on Environmental Quality (Part IV B) has provided specific provisions for the restriction of the pollution of the atmosphere.

1. According to section 23 J, a person who discharges or emits waste into the atmosphere can do so only under a permit under section 23A, and in accordance with standards or criteria as may be prescribed under this act.

This is expanded in Section 23 K (Pollution of atmosphere) It says that no person shall pollute the atmosphere or causes or permit the atmosphere to be polluted so that the physical, chemical or biological condition of the atmosphere is so changed as to make or reasonably be expected to make the atmosphere or any part to become unclean, noxious, poisonous, improve, detrimental to health, welfare, safety or property of human beings, poisonous or harmful to animals, birds, wildlife, plants or all other forms of life or detrimental to any beneficial use of the atmosphere.

Sub section (2) expands this further to include, inter alia,

a. The use of an internal combustion engine or fuel burning equipment not equipped with any device required by the regulations to be fitted to such engine for the prevention of or reduction of pollution. {Section 23 K (2)(d)}.
b. The use of or burning of fuel, which is prohibited by regulations made under this act. {Section 23 K (2)(e)}.

According to the section 23 L anyone who owns, uses, operates, constructs, sells, installs or offers to sell or install any machinery, vehicle or boat required by or under this act or under any regulations made under this act to prevent or limit pollution of the atmosphere does have to build it, fitted with or equip it with such devices and the failure to do so is an offence. This section also says that the devices should be built, fitted or equipped under this section shall be maintained and operated at the cost of the owner.

The definition of air pollution under this act (under Section 33 Interpretations) means an undesirable change in the physical, chemical or biological characteristics of air which will adversely affect plants, animals, human beings and inanimate objects.

The power to make regulations in respect of all matters, which are said or are required by this act, is used with the Minister in charge of the subject {Section 32 (1)}

These provisions taken together, makes it possible to do one or more of the following activities under this act in order to prevent, control or reduce the pollution of air by emissions from motor vehicles.

a. Specify the types of fuel that should be used in motor vehicles.
b. Prohibit certain types of fuel that could lead to higher degree of pollution.
c. Mandate the use of attitudes or treatment methods that will contribute to the reduction of pollution.
d. Prohibit the use of additives or treatment methods that will contribute to the pollution.
e. Emission standards from the vehicles.
f. The requirement to use a type/types of devices to be fitted to an engine to prevent or reduce pollution.
g. The requirements for manufacturers to build, fit or equip vehicles which devices that are needed for the prevention, reduction or controlling pollution.
h. Preventing the use of certain types of machinery, equipment or devices in engines.

The next question that needs be addressed is the probability of implementation of vehicle emission standards at national, regional and local levels. Since the National Environmental Act is a National legislation (as opposed to a statute of a provincial council) any standards that are made under this act by regulations have a nation wide application.

Thus, the National Environmental (Air Emission, Fuel and Vehicle Importation Standards) Regulations No. 01 of 2000 published in gazette extraordinary number 1295/11 of 30.06.2003 are applicable throughout the country. However, there could be regulations to impose stringent standards in cases of necessity, for example to preserve and protect a historically important, geologically important or biologically important site.

These could be implemented by a process of zoning or by a case-by-case basis. Both these types are found in the National Environmental (Protection and Quality) Regulations No. 01 of 1990, published in gazette extra ordinary no. 595/16 of 02.02.1990. According to this, general standards have been provided under registration (2), which have differently standards according to the different receiving environments. Regulation (3) state that not withstanding anything contained in regulation (2), the authority can, by a direction, impose more stringent standards and criteria than these specified in the regulations. A similar type of stringent standards could be imposed when necessary of similar provisions on air emission standards are brought in by regulations.

Taken together it means that present air quality standards, as published in gazette No. 1295/11 have to be adopted through out the country. But, if necessary, it is possible to bring in new regulations that may be needed to give more stringent standards, which may apply, only to specific or special areas. But, these need to be justified by a special need.

It is not possible to have regulations under this act that can be applied to only a particular province, district or a local government body unless there is a strong justification based on above reasons. If not, it will amount to a discrimination, and will be a violation of article 12 (1) of the constitution of the Democratic Socialist Republic of Sri Lanka. Article 12 (1) says that all persons are equal before the low and are entitled to the equal protection of low. This means that when two or more people should be treated equally when similar circumstances are prevailing, or that equals should not be placed unequally. If sets of measures are adapted in a certain locality, which are not applied in other areas, it amounts to the treatment of equals unequally. Thus, it is not possible to even have a pilot programme in a certain area with out being contradictory to this principle.

2.2.3 Statutes of Provincial Councils

Provincial Councils have been established under the thirteenth Amendment to the constitution of the Democratic Socialist Republic of Sri Lanka. Establishment of

provincial councils is provided for under chapter XVII A. Provincial councils have the power to make statutes applicable to a province (Article 154 G), with respect to any matter set out in list I of the Ninth Schedule (designated as the "Provincial Council List") and in respect of any matter set out in list III of the Ninth Schedule. (Designated as the Concurrent List). In addition to the provincial council, the parliament can also make any lows with respect to any matter set out in the Concurrent List after consultation with all provincial councils.

The protection of the environment is a subject that is found in the Concurrent List (item number 33 in the list III of the Ninth Schedule). Thus, it is possible for a provincial Council to pass a statute on environmental protection. A statute on a subject in the Concurrent List can be passed only with the consultation with the Parliament {Article 154G(5) (b)}. In addition, provisions in a statute will be a void if it is inconsistent with the provisions of any low.

It is possible for a regionally applicable law on air emissions to be brought in as part of an environmental statute of a province. It is also possible to have regulations under the statute, which would be applicable only within the province. It is also possible to determine different standards for different categories as found in the National Environmental Act by having regulations.

There is still only one provincial environmental statute. It is the Environmental Statute of the North-Western Provincial Council (North Western province Environmental Statute, No. 12 of 1990). It is similar in scope and extent to the National Environmental Act and the various clauses are basically the same as found in the National Environmental Act. There are three clauses (27, 28 and 29) that are meant to control, manage and prevent the pollution of the atmosphere. The provisions in clause 27 is the same that is found in section 23 J of the National Environmental Act (NEA) while clauses 28 and 29 are the same as sections 23K and 23L of the NEA.

If there is a need to enforce standards of emissions to air in a province, it could be done under a Provincial Environmental Statute. The North Western Province Environmental Statute has the necessary powers and a set of regulations under it can give effect to these sections. Since the other six provincial councils that are functional at present (the North-East Provincial Council being non-functional) one or more of them can pass a statutes followed by appropriate regulations to initiate the programme. Since there are no provincial statutes other than the North-Western Provincial Council the provisions in the NEA apply in all these areas without any changes.

It is therefore possible to implement provisions to control air emission standards within a province by way of an Environmental Statute. However, the body that is empowered with the enforcement would either be a new body established under the statute or even an existing body under the authority of the relevant Provincial Council. The North Western Province Environmental statute has provided for the creation of a North Western Province Environmental Authority to unforced the provisions of the statute. (Parts I, II and III of the statute)

However, it is not possible for Provincial Council to make these provisions apply for only a particular district, city or local government authority area. A set of special standards could be made to apply to such an area if there is a compelling reason such as a site of archaeological, geological or biological value that needs to be provided with a special degree of protection. If sets of regulations are to be applied only within a specific area without any compelling reason, it will amount to discrimination, which will be a violation of Article 12(1) of the constitution of the Democratic Socialist Republic of Sri Lanka.

2.2.4 Motor Traffic Act

This act provides for, among other things, the use of motor vehicles on highways and relating to motor vehicles and the regulating of passengers carriage services and the carriage of good by motor vehicles. It is a broad-based act that deals with many different aspects regarding motor vehicles. Part IX of this act deals with the examination, inspection and testing of motor vehicles.

According to section 194(1), the commissioner can require a motor vehicle to be inspected and examined for, among other things,

a. To ascertain whether a motor vehicle has been in compliance with the requirements laid down under this act or regulations made under it.
b. That information furnished in respect of a motor vehicle is correct, incorrect, true or false.
c. Whether it is not in a serviceable condition.

When the commissioner is satisfied after an inspection and examination of a motor vehicle that it does not comply with the requirements of this act or any regulations, can issue a notice on the owner prohibiting the use of the vehicle until the commissioner is satisfied after another inspection and examination, that the defects specified in the notice have been corrected. In addition, the commissioner can even order that the revenue license to be surrendered to him in order to impound it until the measure given in the notice have been complied with. According to section 202, regulations can be made prescribing the methods that have to be followed and the tests that need to be applied in the examination of motor vehicles and the nature of the reports that need to be furnished after such examinations under this act. These provisions, taken together, make a possible to get all owners of motor vehicles to adapt necessary measures to control, regulate and reduce those emissions that can lead to the pollution of the atmosphere.

However, these measures have to be applied similarly in all parts of the country. The only possibility of making differences has to be based only on the type and nature of the vehicle and not on other factors. It is not possible to have it imposed on any particular area as a pilot project because it will infringe the provisions in Article 12(1) of the constitution of the Democratic Socialist Republic of Sri Lanka.

REFERENCES

1. Bulankulama and six others vs. Secretary, Ministry of Industrial Development and seven others, S.C. Application No. 884/99(F/R)

2. Gunaratne vs. Homagama Pradeshiya Sabha (1998) 2 Sri Lanka Law Report 11.

3. Motor Traffic Act (Chapter 203) Incorporating amendments up to 30th September 1990.

4. Motor Traffic (Amendment) Act No. 44 of 1992

5. Motor Traffic (Amendment) Act No. 5 of 1998

6. National Environmental Act No. 47 of 1980

7. National Environmental Act (Amendment) No. 56 of 1988

8. National Environmental Act (Amendment) No. 53 of 2000

9. North Western Provincial Environmental Statute No. 12 of 1990

10. Regulations, 1137/35 of 23.06.2000, 595/16 of 02.02.1990, 742 of 20.11.1992 and 1295/11 of 30.06.2003

11. Special Determinations of the Supreme Court Nos. 14/2003, 15/2003 and 16/2003

12. The constitution of the Democratic Socialist Republic of Sri Lanka and the thirteenth amendment

Chapter - 3

VEHICLE EMISSION REDUCTION

3.1 BACKGROUND AND OBJECTIVES

3.1.1 Background

The study on Vehicle Emission Reduction in Sri Lanka was conducted within the overall framework of the Urban Air Quality Management Project. The overall objective of the project was to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions. The purpose of this component of the study was to strengthen the institutional and policy framework for urban air quality management in Colombo. The study was undertaken by the international consultant "Engine, Fuels, and Emission Engineering Inc. (EF&EE)", USA. The local consultant of the project is Thermo-Fluids & Energy Group, University of Moratuwa.

In addition to the main consultancy, a legal consultant was hired to look at the possibility of implementing the Vehicle Emission Standards in Sri Lanka by reviewing the legal provisions under National Environmental Act and Motor Traffic Act, with respect to implementation at national, provincial and local level.

3.1.2 Objectives

The main broad objectives of the Vehicle Emissions Reduction project are:

- To Design and carryout a pilot program for measuring emissions from in-use vehicles and analysis of data.
- To revise the vehicle emission standards and vehicle import policy.
- To design of a vehicle inspection and maintenance program.
- To develop a program for training of technicians.

Number of activities was assigned to achieve the above broad objectives of the study. The main activities of the Vehicle Emissions Reduction Component could be summarized as follows:

- Review of data on current and projected future vehicle fleet in Sri Lanka.
- Formulate and assist in implementing a pilot program for measuring smoke emissions from in-use trucks and the emissions of carbon monoxide (CO), hydrocarbons (HC) and smoke from in-use two- and three-wheelers. In particular,

  - identify the most suitable emissions measurement equipment for each,
  - train the personnel in the operation and maintenance of the monitoring equipment;
  - train the trainers for inspection;
  - write a manual for procedures and proper maintenance and calibration of the monitoring equipment;
  - develop a record keeping procedure for the test results that would be amenable to analysis;
  - evaluate the current vehicle registration system for the purpose of establishing an effective inspection and maintenance (I/M) program, and make recommendations for, and estimate costs of making, changes needed, if any;
  - develop procedures for other tests to be conducted at the vehicle villages (for example, visual inspection for safety checks) for the completion of method development;
- Establish criteria for selecting vehicles to be tested for inspection as well as the incentive structure for drivers to participate in this pilot program;
- Evaluate the current vehicle import policy from the point of view of emissions reduction;
- Organize pilot training of mechanics;
- Analyze the emissions data collected and propose future vehicle emission standards, in-use as well as new, including a schedule for phasing in increasingly tighter standards;
- Propose a vehicle inspection system in the Western Province: assist the Government of Sri Lanka in finalising the plan for setting up vehicle villages; identify and cost monitoring equipment required, and level of staffing and training needed. Estimate the overall cost (initial capital as well as annual running costs);
- Evaluate the preparedness of vehicle repair shops in terms of equipment and staffing for adequate vehicle maintenance and repair for compliance with the proposed emission standards;
- Propose how to deal with non-compliance;
- Assess measures for reducing emissions from two-stroke engine vehicles, including supply of 2T oil;
- Incorporate lessons from other developing countries.

3.2. VEHICLE-RELATED AIR POLLUTANTS AND PUBLIC HEALTH

This section briefly summarizes the major air pollutants associated with vehicle emissions, their effects on human health and welfare, and the available data concerning their concentrations in Colombo. Air pollutants associated with vehicle emissions include respirable particulate matter (PM), lead aerosol, oxides of nitrogen (NOx), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), and volatile organic compounds (VOC). This latter group of compounds includes toxic and carcinogenic organic species such as benzene, formaldehyde, and 1,3 butadiene. Of these pollutants, risk assessments in a number of cities in the developing world have shown that the most damaging to public health are PM and lead aerosol (where lead antiknocks are still allowed to be used in petrol). Since Sri Lanka recently eliminated the use of lead additives, lead aerosol is not expected to pose a significant threat to public health in future.

Important sources of ambient PM include direct emissions of smoke and dust, resuspended dust, and the formation of sulfate and nitrate particles from SO_2 and NOx in the atmosphere. Ozone, produced by photochemical reactions between NOx and VOC, is also responsible for significant health impacts in some cities. Figure 1 diagrams the relationships between the emission of air pollutants and the main pollutant species found in the atmosphere.

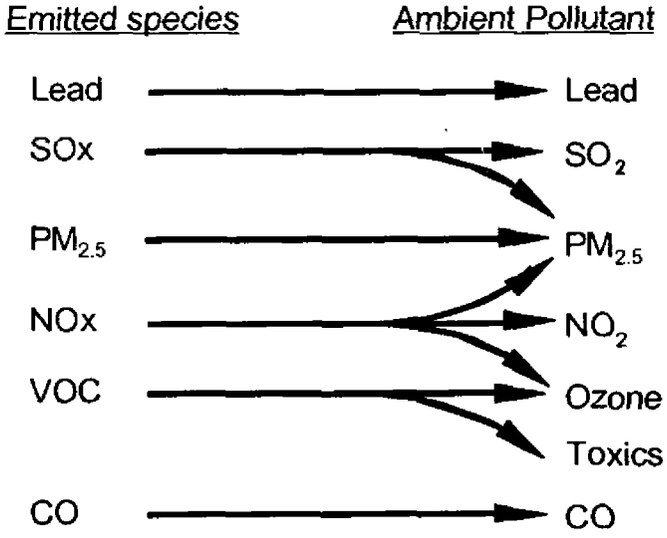


Figure 3.1: Relationship between ambient air pollutants and emitted pollutants

3.2.1 Particulate Matter

High levels of suspended PM are a significant threat to public health in Colombo and many other cities of the developing world. In the past, concern centered on total suspended particulate matter (TSP). However, health studies have shown that the risks of PM exposure are much greater for very fine particles than for coarser ones such as dust particles, which are readily filtered out by the nasal system. Monitoring and regulations are therefore focused in *respirable* particulate matter less than 10 μm in aerodynamic diameter, commonly referred to as PM10.

Particles in the PM10 size range can be further divided into a *fine* fraction less than 2.5 μm in aerodynamic diameter, and a *coarse* fraction between 2.5 and 10 μm. Recent studies show that most of the health impacts of PM10 are due to the fine fraction, often referred to as PM2.5. The sources and composition of these two fractions are very different: most of the material in the coarse fraction consists of soil particles, while the fine fraction is made up mostly of soot and condensed organic compounds from combustion sources, along with nitrate and sulfate particles formed in the atmosphere. In typical cities, PM2.5 accounts for 50 to 60% of the total PM10.

Clear statistical links have been established between PM10 and PM2.5 concentrations and a variety of health problems, including premature mortality, asthma, chronic bronchitis, and increased susceptibility to respiratory disease. An extensive review of the epidemiological data on PM exposure was performed by the U.S. Environmental Protection Agency (EPA) in the process of developing its revised National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter[3]. Two key conclusions of the EPA review were that the risk of premature death due to PM exposure is more closely related to PM2.5 than to PM10 concentrations, and that these risks are much higher than previously estimated.

The key dose-response coefficients from the EPA study are shown in Table 1. The EPA analysis of results from short-term (longitudinal) studies shows that a 10 $\mu g/m^3$ increase in daily average PM2.5 concentrations is associated with an increase of 1.44% in the daily mortality rate in a given city. For comparison, a 10 $\mu g/m^3$ increase in ambient PM10 is linked to a 0.79 percent increase in mortality. These values are based mostly on results from Europe and the U.S. Ambient PM effects may be even greater in developing countries, where building windows are often open, and people spend more time outdoors. A recent epidemiological study in Bangkok[4] showed that a 30 $\mu g/m^3$ increase in daily PM10 concentration was correlated with a 3 to 5% increase in daily mortality.

The effects of chronic exposure to high PM2.5 concentrations may be even more damaging. The EPA cites one cross-sectional study comparing the effects of long-term PM exposures in six cities, which associated a 10 $\mu g/m^3$ increase in annual average PM2.5 exposure with a 6.6% increase in mortality. On the basis of these and the short-term exposure results, the U.S. EPA established new ambient air quality standards of 15 $\mu g/m^3$ for annual average PM2.5 concentrations and 65 $\mu g/m^3$ for daily average PM2.5.

In addition to premature death, exposure to high PM concentrations is associated with increased risk of suffering a variety of respiratory and related illnesses, ranging from colds and flu to asthma, pneumonia, and chronic bronchitis. Estimates of the increased risks in developing nations are given in a study by Maddison and coworkers at the World Bank[5].

Table 3.1: U.S. EPA dose-response estimates for PM10 and PM2.5

	Population Affected	Log-Linear Coefficient	Delta Mortality Per 10 μg/m³
PM2.5 Short Term	All	0.001433	1.44%
PM2.5 Long Term	30+	0.006408	6.62%
PM10 Short Term	All	0.000782	0.79%

Major sources of PM2.5 emissions in Colombo, as in other cities of the developing world, include soot and condensed vapors from combustion in vehicles (especially diesel vehicles and two-stroke motorcycles), stationary combustors, and open burning of domestic and agricultural wastes. Sources in the earth's crust, such as windblown dust from eroded and deforested areas, and dust stirred up by vehicular traffic along roads (known as "re-entrained" dust), account for the bulk of the "coarse" PM10 fraction, but usually less than 30% of the fine fraction. Particulate emissions are also produced in uncontrolled industrial processes such as smelting and processing of non-metallic minerals. In addition, fine sulfate, nitrate, and organic particles are produced in the atmosphere by photochemical processes. Such "secondary" particles make up a significant fraction of the ambient PM2.5 in many cities, but probably not in Colombo, due to the relatively good ventilation experienced.

High levels of suspended particulate material are the major cause of the degraded visibility associated with air pollution. This may adversely affect tourism, as well as the people's enjoyment of their own city. High particulate levels also contribute to soiling of buildings and public monuments, and the acidity of the sulfate and nitrate components of the particulate matter causes corrosion and materials damage.

Quantitative data on PM2.5 and PM10 concentrations in Colombo were not available for this study. Qualitatively and subjectively, however, the levels of visible smoke and fine particulate matter along major traffic routes in Colombo appear to be of the same order as to those observed in other major cities – such as Bangkok and Santo Domingo – for which quantitative PM2.5 data *are* available, and show exceedance of the U.S. EPA's PM2.5 standard. From this, we consider it safe to assume that PM2.5 concentrations in central Colombo and along major roads are high enough to present a significant risk to public health.

3.2.2 Lead Aerosol

The health impacts of lead in the environment have been reviewed by Lovei[6], WHO[7], the U.S. EPA[8], and California Air Resources Board[9]. An impressive array of evidence has been accumulated linking even subacute blood lead levels with a variety of ills, including reduced mental capacity in children and high blood pressure in adults. The U.S. Surgeon General recently revised the level of lead in blood at which medical action is recommended from 25 ìg/deciliter to 10 ìg/deciliter. This is considerably below the *average* blood lead level among urban dwellers in many developing countries.

Routes of human exposure to lead include food (solder in cans), drinking water (lead pipes), and dust from lead paint. By far the most important exposure route, however, is by inhalation of lead aerosol. Lead antiknocks in gasoline are by far the largest source of lead aerosol. Experiences in the U.S., Mexico, and Thailand have shown a strong and direct correlation between the consumption of lead in gasoline, ambient levels of lead in the atmosphere, and average blood lead levels in children and adults. For example, efforts by Petroleos Mexicanos to reduce the lead concentration in gasolines sold in Mexico City have reduced ambient lead concentrations by more than 98%, and average blood lead concentrations by more than 50% since 1988[10]. In Bangkok, the phaseout of leaded gasoline reduced average airborne lead concentrations from 0.50 $\mu g/m^3$ in 1990 to 0.07 $\mu g/m^3$ in 1997[11]. With Government's recent decision to eliminate leaded gasoline use in Sri Lanka, we expect lead concentrations in ambient air and in human blood to experience a similar precipitous decline.

3.2.3 Ozone

Ozone is a "secondary" pollutant, formed by the reaction of "primary" directly-emitted pollutants in the atmosphere. It is the marker chemical for a family of photochemical oxidants produced by chemical reactions in the atmosphere between oxides of nitrogen (NOx), unburned hydrocarbons and other volatile organic compounds (VOC) in the presence of sunlight. Other, related chemical reactions involving NOx, VOC, and ozone result in the production of organic, sulfate, and nitrate particles, gaseous nitric acid, peroxy-acetyl nitrate (PAN), and other secondary pollutants which normally accompany high ozone concentrations.

Either NOx or VOC may be the limiting factor in ozone production in a given situation. A common rule-of-thumb is that in situations with VOC:NOx ratios greater than 10:1, ozone production is limited by the availability of NOx and reductions in VOC (unless very large) have little effect on ozone production. Where the VOC:NOx ratio is less than 8:1, ozone is VOC-limited, and reducing NOx may even increase local ozone concentrations. For ratios between 8:1 and 10:1, both NOx and VOC are significant.

Short-term exposure to high ambient ozone concentrations causes irritation and inflammation of the eyes and respiratory tract, increased mucous production, and a decrease in lung function, especially in sensitive individuals. Lassitude, irritability, and nausea have also been reported. Recent research data from Los Angeles indicate that long-term exposure to the oxidizing effects of ozone may lead to premature aging of the lung and a permanent loss of lung capacity. Persons with increased sensitivity to ozone include young children, athletes and persons with asthma or other respiratory disorders; in sensitive individuals, adverse reactions to ozone have been detected even at levels near or below the present health-based air quality norms, suggesting that these norms may not provide complete protection to all members of the community.

In addition to effects on human health and well-being, high ambient ozone concentrations adversely affect vegetation, rubber and plastics, and surface coating such as paints. Exposure to ozone reduces growth rates in trees and agricultural crops, and renders them more susceptible to disease. High regional ozone levels are now suspected to be the major factor in the decline of forests in Europe and the Eastern United States, initially attributed to acid rain. Ozone attacks and embrittles rubber and plastics exposed to it, and can cause premature oxidation and fading of paints and other pigments.

3.2.4 Carbon Monoxide

Carbon monoxide (CO) is formed by the incomplete combustion of carbon-containing fuels. In most cities of the developing world, nearly all of the CO emissions are produced by gasoline vehicles (wood and coal stoves used for home heating in cold climates are the other main source). In total mass of emissions, CO far outweighs all other pollutants combined. Because CO is emitted primarily by vehicles, local CO "hot spots" near heavily congested roads and intersections may experience dangerously high levels, even though the levels measured by nearby air-quality monitors are not excessive.

When inhaled, CO binds to hemoglobin in the blood to form carboxyhemoglobin. This deactivates the hemoglobin molecule, preventing the transport of oxygen through the body, and reducing the oxygen supply to sensitive tissues such as the brain, heart and linings of blood vessels. The results of moderate CO toxicity include shortness of breath, increased blood pressure, headaches, and difficulty in concentration. CO effects are most significant in pregnant women, young children and those suffering from heart or respiratory disease.

3.2.5 Nitrogen Dioxide

NO_2 plays a key role in the photochemical production of ozone. It is also a toxic and irritant gas, and the precursor to formation of nitric acid and nitrate particles, which are significant contributors to acid deposition and ambient PM2.5 levels. Some NO_2 is directly emitted as a result of combustion. However, most NOx from combustion sources is emitted in the less toxic form of NO. This is subsequently oxidized to NO_2 as part of the same photochemical cycle that produces ozone.

Short-term exposure to high levels of NO_2 causes lung edema and damage to lung cells, increasing susceptibility to bronchial infections. NO_2 also acts as a bronchoconstrictor, aggravating asthmatic conditions. Longer-term exposure to lower levels of NO_2 can cause changes in the lung tissues similar to emphysema, some of which are irreversible.

NO_2 has a distinctive brownish color and accounts for part of the brownish color of the air during episodes of heavy pollution. Nitric acid vapor and nitrate particles also contribute to degrading visibility and to corroding materials exposed to them.

3.2.6 Sulfur Dioxide

SO_2 is produced by the combustion of sulfur-containing fuels such as coal and residual oil, and - to a much lesser degree, from smelting of sulfide ores and other processes. In the atmosphere, SO_2 reacts with ozone and other photochemical oxidants to produce SO_3, which rapidly combines with water to form sulfuric acid and with various cations to form sulfate particles. These secondary particles contribute to ambient PM2.5 concentrations.

SO_2 is absorbed primarily in the nasal system - little of it reaches the lungs. The effects of exposure to high short-term concentrations include irritation of the respiratory tract, bronchitis, and bronchoconstriction in asthmatics. Exposure for 24 hours to SO_2 above 0.09 ppm, or long-term exposure to 0.04 ppm, in conjunction with acid aerosols and other particulates, has been cor-

related with increases in respiratory illness. Like NO_2, SO_2 is a significant contributor to ambient PM2.5 levels, with adverse effects on visibility, and to acid deposition.

3.2.7 Toxic Air Contaminants

Analyses carried out in the United States show that the most significant population exposure to toxic air contaminants comes as a result of vehicular emissions. The same is probably true in developing countries, since emissions of toxic air contaminants are related to total HC emissions, and vehicular HC emissions tend to be much higher in developing countries than in the U.S.

3.3. ASSESSMENT OF VEHICLE FLEET DATA AND VEHICLE IMPORT POLICY

Two of the tasks defined in the Terms of Reference are to

> "Review the work of the local consultant to be procured under separate terms of reference who will be collecting and analyzing data in Sri Lanka on current and projected future vehicle fleet size, characteristics (age distribution, fuel use, origin), type of valve seat (soft or hard, for the purpose of determining the need for lubricant additives after gasoline lead elimination), and octane requirements (as specified by vehicle manufacturers). Oversee the completion of this assignment and include in the analysis development of vehicle mortality curves"

and

> "Evaluate the current vehicle import policy from the point of view of emissions reduction"

This section outlines the progress achieved and the issues identified in these two tasks during the Inception Mission.

3.3.1 Vehicle Fleet Data

The local consultants prepared a report on vehicle fleet numbers and population projections[12]. As part of this study, they compiled data on the total number of vehicles registered to date by the Department of Motor Traffic. In 2000, this amounted to 1,705979 and the number had nearly doubled since 1991. Unfortunately, this figure includes many vehicles that are no longer in active service, as the Department of Motor Traffic does not record when vehicles are removed from the active fleet. Annual vehicle registration is carried out at District offices, rather than the Department, and the registration data are not collected and compiled to identify vehicles no longer in service. Thus, the data compiled by the Department and the local consultants cannot be used directly to determine the size or age distribution of the active vehicle fleet. Neither can these data be used to develop vehicle mortality curves. Estimates of the number of vehicles in active service have been developed based on license plate surveys. On this basis, the Department of Motor Traffic cites an estimate of 950,000 vehicles for the active fleet in 2000[13]. Dr. Jayaweera[14] gives an estimate of 1,164,173 vehicles in the active fleet in the year 2000, and also gives a breakdown by vehicle and fuel type. From discussions with Dr. Jayaweera, we learned that the data given in his paper were preliminary results from a more extensive study by Dr. A.K. Kumarage, which included the development of mortality curves and a vehicle fleet model. The local consultants also relied on Dr. Kumarage's study to estimate the active road vehicle fleet in 2000 at 1,100,000 vehicles (plus another 105,000 "land vehicles" not intended for on-road operation); and to project active road vehicle populations

between 1,273,000 to 1,672,000 vehicles in 2005, based on lower or higher assumptions concerning economic growth in the interim. Updated results from Dr. Kumarage's study were recently provided to us[15], and we understand that the complete study is to be published within a few months. The resulting estimates of the active Sri Lankan road vehicle fleet are given in Table 3.2. These results are generally similar to the projections developed by the local consultants, but appear to be more recent, and we have therefore adopted them for this study.

Table 3.2: Estimated active Sri Lanka vehicle fleet in 2000 and 2005

Vehicle Class	Active Road Vehicle Fleet	
	2000	2005
Diesel Vehicles		
Lorries	64,994	75,363
Buses	23,809	27,607
Passenger Cars	19,585	29,108
Dual-Purpose Veh	182,568	271,349
3-Wheeler	3,675	4,719
Petrol and LPG Vehicles		
Passenger Cars	130,136	193,419
Dual-Purpose Veh	24,431	36,311
Petrol 3-Wheel	73,176	93,956
Motorcycle - 4T	373,642	479,745
Motorcycle - 2T	177,054	227,332
Total road vehicles	1,073,070	1,438,910

Source: reference 16

Air pollution control policy must account for the intensity and location of vehicle use, as well as the numbers in the fleet. Because of their intensive use and concentration in urban areas, commercial vehicles such as trucks, buses, three-wheelers, and dual-purpose vehicles used for public transportation contribute disproportionately to urban air pollution. On the other hand, motorcycles appear much more common in the countryside than in the city, and thus probably contribute much less to urban air pollution levels, despite their high emission levels.

3.3.2 Vehicle Import Policy

Sri Lanka has little domestic vehicle industry – thus, virtually 100% of the vehicles that come into service in the country are imported. The Government's vehicle import policy thus determines not only trade issues, but also determines the composition, characteristics, and rate of growth of the vehicle fleet as a whole.

A detailed description of the Government's vehicle import policy was to have been prepared by the local consultants, but has not been received. However, we did gain a general understanding of the policy in the course of our meetings during the inception mission. Vehicles may be imported either new or used. For used vehicles, there is an age limit: either three years (for passenger cars, three-wheelers, and dual-purpose vehicles) or 5 years (for heavy trucks, buses, and "land vehicles"). Because of their substantially lower costs, the great majority of the vehicles imported to Sri Lanka are used. Bowing to competitive pressure, even

many of the authorized distributors of new vehicles have begun to import and sell "reconditioned" used vehicles as well.

Before entering service, imported vehicles must be inspected by the Department of Motor Traffic to establish weights and identifying information, and to confirm compliance with applicable equipment and safety laws. New vehicles are inspected on a "prototype" basis - the authorized importer presents a single prototype of each model to the Department for inspection, whereupon all new vehicles of that model are considered accepted. For vehicles that are imported used, the Department requires that each vehicle be inspected separately to assure compliance with applicable laws. Although this could include a check for emissions in excess of permitted levels, it does not appear that the equipment to perform such checks is routinely available to the inspectors.

3.3.3 Emission Standards

Emission standards for imported vehicles have been published by the Ministry of Environment[16], and were scheduled to take effect on January 1, 2003. At that time, vehicles were to be required to comply with the emission standards established by the European Union, or else another standard that is within the emission limits established by the following European Union directives:

- For motor coaches and lorries, Commission Directive 96/69/EC;
- For motor cars, Commission Directive 94/12/EC; and
- For motorcycles and three-wheelers, Commission Directive 97/24/EC.

The emission limits established in the present Sri Lankan regulations for motor coaches, lorries, and motor cars are more strict than those in effect in most of India, and are comparable to those that apply to vehicles sold in India's National Capital Region. However, our understanding is that these standards are not yet being enforced effectively.

The Vehicle Emission Control Committee is considering further amendments to the emission standards. Unfortunately, in many cases, the European Union regulations cited in the draft of the proposed amendments provided to us in November, 2002 do not apply to the class of vehicles in question. With a view to clarifying the issues involved, this section summarizes existing E.U. standards for vehicle emissions, and recommends standards to be adopted by Sri Lanka.

3.3.3.1 Motorcycles and Three-Wheelers

Table 3 compares the different European and Indian emission standards for motorcycles and three-wheelers. As this table shows, the E.U. regulations for this class of vehicles were comparatively lax until recently, reflecting the relatively low importance of motorcycles and three-wheelers as sources of emissions in Europe. These vehicles account for a much more significant portion of total vehicular emissions in India and Sri Lanka. Since the great majority of motorcycles and three-wheelers sold in Sri Lanka are of Indian origin, it would seem reasonable for the country to adopt the stronger Indian emission standards. As discussed in section 3.4, however, we would recommend prohibiting the importation of diesel two- or three-

wheelers, regardless of emission standards, unless equipped with effective diesel particulate filters.

Table 3.3: European and Indian emission standards for motorcycles and three-wheelers

	CO (g/km)	HC (g/km)	NOx (g/km)	
E.U. Directive 97/24/EC ("Euro I")				
Two-Stroke	8.0	4.0	0.1	
Four-Stroke	13.0	3.0	0.3	
E.U Directive 2002/51/EC (2003 - "Euro II")				
I: < 150 cm³	5.5	1.2	0.3	
II: ≥ 150 cm³	5.5	1.0	0.3	
E.U Directive 2002/51/EC (2006 - "Euro III")				
I: < 150 cm³	2.0	0.8	0.15	
II: ≥ 150 cm³	2.0	0.3	0.15	
Indian Rule 115 (effective 1.4.2000)				
	CO (g/km)	**HC+NOx (g/km)**	**PM (g/km)**	**Idle CO (%)**
Two-wheelers	2	2	N/R	4.5
Three-wheelers (petrol)	4	2	N/R	4.5
Three-wheelers (diesel)	2.72	0.97	0.14*	N/R

*Also smoke limits of 2.26 m^{-1} at full load and 2.45 m^{-1} in free acceleration

3.3.3.2 Light-Duty Vehicles

Light-duty vehicles comprise motor cars and "dual-purpose" vehicles such as pickup trucks and small vans. Most dual-purpose vehicles are treated as "light commercial" vehicles in E.U. emission regulations. These light commercial vehicles are probably the single largest contributor to the urban air pollution problem in Sri Lanka. The regulations in Commission Directive 94/12/EC (Table 3.4) left in place the then-existing emission standards for light commercial vehicles, which had been given in Directive 93/59/EEC (Table 3.5). These standards are notably less strict than those for passenger cars. We would therefore recommend applying the emission standards contained in the later Commission Directive 96/69/EC, which are listed in Table 3.6. This latter directive retained the limits of Directive 94/12/EC for passenger cars, and extended similarly strict emission standards to light commercial vehicles. As discussed in Section 3.4, we would further recommend a complete prohibition on further imports of light-duty diesel vehicles (regardless of emissions standard) unless equipped with an effective diesel particulate filter capable of tolerating the high sulfur levels in Sri Lankan diesel fuel.

Table 3.4: European emission standards for passenger cars

	91/441/EEC		94/12/EC[1]	
	Type-Approval	Conformity of Production	Gasoline	Diesel
CO (g/km)	2.72	3.16	2.2	1.0
HC + NO_x (g/km)	0.97	1.13	0.5	0.7[2]
Diesel PM (g/km)	0.14	0.18	N/A	0.08[3]
Evap. Emissions	2.0 g/test		2.0 g/test	N/A

[1] Directive 94/12/EC applies to both type approval and conformity of production

[2] 0.9 g/km for DI diesels until September 1999

[3] 0.10 g/km for DI diesels until September 1999

Table 3.5: 93/59/EEC emission standards for light commercial vehicles

Vehicle Type[1]	Type Approval (g/km)			Conformity of Production (g/km)		
(N_1)	CO	HC+NOx	PM^2	CO	HC+NOx	PM^2
I: RW ≤ 1,250	2.72	0.97	0.14	3.16	1.13	0.18
II: 1,250 < RW ≤ 1,700	5.17	1.40	0.19	6.0	1.6	0.22
III: 1,700 < RW	6.9	1.7	0.25	8.0	2.0	0.29

[1] Also applies to vehicles designed to carry more than six persons including the driver and vehicles with maximum mass exceeding 2500 kg

[2] Applies to diesels only.

Table 3.6: 96/69/EC Euro 2 emission limits for passenger cars and light commercial vehicles

Effective Date		Vehicle[1]		Limit Values		
New Type Approvals	New Registrations	Reference Mass (kg)	Type	CO (g/km)	HC+NOx (g/km)	PM (g/km)
Jan 1, 1996	Jan 1, 1997	Category M^3 Passenger Cars	Gasoline	2.2	0.5	-
			IDI Diesel	1.0	0.7	0.08
			DI Diesel[2]	1.0	0.9	0.10
Jan 1, 1997	Oct 1, 1997	Class I Category N_1 ≤ 1250	Gasoline	2.2	0.5	-
			IDI Diesel	1.0	0.7	0.08
			DI Diesel[2]	1.0	0.9	0.10
Jan 1, 1998	Oct 1, 1998	Class II Category N_1 1251-1700	Gasoline	4.0	0.6	-
			IDI Diesel	1.25	1.0	0.12
			DI Diesel[2]	1.25	1.3	0.14
Jan 1, 1998	Oct 1, 1998	Class III Category N_1 > 1700	Gasoline	5.0	0.7	-
			IDI Diesel	1.5	1.2	0.17
			DI Diesel[2]	1.5	1.6	0.20

[1] Also applies to vehicles designed to carry more than six persons including the driver and vehicles with maximum mass exceeding 2500 kg [2] Until September 30, 1999 then IDI Diesel rules apply

3.3.3.3 Heavy-Duty Vehicles

E.U. Commission Directive 96/69/EC is referenced in the Sri Lankan regulations for emissions from heavy-duty vehicles, and Directive 93/59/EC is referenced in proposed amendments to the regulations. Unfortunately, both of these directives apply to light commercial vehicles, and not to heavy-duty trucks and buses. The European heavy-duty vehicle regulations are summarized in Table 7 and Table 8. The Euro II regulations took effect in Europe from October, 1996, with further tightening of the PM standard from .25 to .15 g/kWh in October 1998. Similar or identical requirements have also been adopted in Thailand, parts of India, and parts of Latin America. The Euro III standards took effect in October, 2000 in Europe. The Euro IV standards will take effect in October, 2005; while Euro V standards are scheduled to be effective in October, 2008.

The Euro II emission standards represent a significant improvement over engines without emission control - especially for PM emissions, which are the pollutant of greatest concern for Sri Lanka. Vehicles equipped with engines designed to meet these standards are also widespread throughout the world. These would seem to make the Euro II regulations a natural choice for Sri Lanka. Some words of caution are needed, however. Although it is possible to

achieve the Euro II emission limits with mechanical engine controls, many engine manufacturers chose to introduce electronic engine control systems to meet these limits. Such electronic systems can be programmed to "defeat" the emission standards by detecting whether the engine is operating under the conditions specified in the test cycle. If not, the control system changes the injection timing and other control variables to optimize for fuel economy and power output, rather than emissions.

Table 3.7: European Union regulations for heavy-duty vehicle engines, Euro 0 - Euro II

Regulations	Test Cycle	Exhaust Emissions (g/kwh)							
		Type Approval				Conformity of Production			
		HC	NO_x	CO	PM	HC	NO_x	CO	PM
88/77/EEC	ECE R-49	2.4	14.4	11.2	NR	2.64	15.8	13.2	NR
91/542/EEC(Euro I)	ECE R-49	1.1	8.0	4.5	0.36[1]	1.23	9.0	4.9	0.4[1]
91/542/EEC (Euro II)	ECE R-49	1.1	7.0	4.0	0.15	1.1	7.0	4.0	0.15

NR: not regulated

[1] In the case of engines of 85 kw or less, the limit value for particulate emissions is increased by multiplying the quoted limit by a coefficient of 1.7 Engines must also comply with ECE R24-03 smoke standards.

Table 3.8: European Union regulations for heavy-duty vehicle engines, Euro III - V

Regulations	Test Cycle	Exhaust Emissions (g/kwh)				Smoke (m^{-1})
		HC	NOx	CO	PM	
1999/96/EC (Euro III)	ESC & ELR	0.66	5.0	2.1	0.10 / 0.13[1]	0.8
	ETC	0.78[2]	5.0	5.45	0.16 / 0.21[1]	NR
1999/96/EC (Euro IV)	ESC & ELR	0.46	3.5	1.5	0.02	0.5
	ETC	0.55[2]	3.5	4.0	0.03	NR
1999/96/EC (Euro V)	ESC & ELR	0.46	2.0	1.5	0.02	0.5
	ETC	0.55[2]	2.0	4.0	0.03	NR

NR: not regulated ESC: European Stationary Cycle ELR: European Load Response
ETC: European Transient Cycle

[1] For engines having swept volume less than 0.75 dm^3 per cylinder and rated-power speed more than 3,000 RPM

[2] non-methane HC

The widespread use of such software "defeat devices" resulted in a major scandal in the U.S. in 1998. We have also observed what appear to be the effects of such practices in heavy-duty diesel engines sold in Mexico, and in "Euro II" diesel engines sold in Thailand. Recent reports also indicate that such devices have been found in European engines. When tested in a realistic driving cycle in Bangkok, emissions from two out of three models of "Euro II" diesel engines sold in Thailand actually had higher emissions than the uncontrolled diesels that they were replacing.

The use of "defeat" strategies in engine emission controls has long been illegal under U.S. law, but was nonetheless common until recently. E.U. regulations outlawing such practices were adopted with Directive 1999/96/EC, and apply to Euro III and later engines; but apparently not to engines subject to the Euro II standards. We recommend, therefore, that Sri Lanka allow importation of Euro II engines only if these have mechanical engine control systems, or are

otherwise demonstrated to comply with the prohibition on "irrational" emission control strategies contained in Directive 1999/96/EC.

3.3.3.4 Other Equivalent Emission Standards

Sri Lanka has opted to standardize on European emission standards and legislation. While this has certain advantages, it should be recognized that the North America and Japan have also established comprehensive systems of emission standards that differ in detail from those adopted in Europe, but which achieve similar or superior levels of emission control in practice. From the standpoint of air quality policy, there is no reason to exclude Japanese or North American vehicles that achieve similar or better emission levels, even though they may not have been certified using the test procedures and standards established in the European legislation. Since a very large fraction of Sri Lanka's vehicle imports presently come as used vehicles from Japan, the argument for accepting equivalent Japanese standards is especially strong. Therefore, we recommend that vehicle emission regulations specify that imported vehicles meet the stated European standards, or "equivalent emission standards of other jurisdictions", as determined by the Motor Vehicle Department. Technical assistance to the Motor Vehicle Department in evaluating such equivalence could be provided by a qualified consultant, such as the technical support contractor that we recommend for the I/M program.

3.3.4 Used Vehicle Import Policy

The Government's policy to allow importation of used vehicles is controversial. Many persons consider that such a policy is likely to lead to higher air pollution, as "old" vehicles are assumed to have higher emissions than "new" ones. However, this is not necessarily the case. Most of the used vehicles sold in Sri Lanka come from Japan, and would therefore have been constructed to meet Japanese emission standards. A three-year-old vehicle built and maintained to these relatively strict emission standards may well have lower emissions than a brand-new vehicle that barely meets Sri Lankan emission limits. Furthermore, the commercial availability of relatively new used vehicles in good condition will tend to reduce the value and encourage the retirement of the large number of very old vehicles in the present Sri Lankan vehicle fleet. Thus, as long as their quality and emissions performance are adequately controlled, permitting used vehicle imports is likely to benefit, and not degrade air quality.

Notwithstanding the foregoing general evaluation, the Government may still wish to restrict imports of specific types of vehicles, used or new. Two types of vehicles for which we recommend such restrictions are light-duty diesels and two-stroke petrol engines. The reasoning behind these recommendations is discussed in Section 3.4.

3.4. NEAR-TERM MEASURES TO CONTROL VEHICLE EMISSIONS

Discussions during the Inception Mission identified several steps that the Government could take in the near term to reduce vehicle emissions and the consequent impacts on public health. In addition to the development of a vehicle inspection and maintenance program (discussed in Section 3.5), these steps included: eliminating lead additives from petrol, planning to reduce diesel fuel sulfur content, and prohibiting further import of two-stroke petrol vehicles and light-duty diesel vehicles. The substitution of natural gas for diesel fuel was also identified as holding future promise, but would not be cost-effective except as part of a much larger-scale effort to employ liquefied natural gas as a fuel in Sri Lanka. The rationale behind these recommendations was documented in a memorandum dated December 21, 2001, and in our inception report of February, 2002.

One of these recommended policies – the elimination of lead additives from petrol – has already been adopted by the Government; while the recommendation to prohibit further importation of two-stroke vehicles is being debated by the Vehicle Emissions Control Committee. A reduction in allowable diesel fuel sulfur content has also been proposed by the Committee. Standards for petrol and diesel fuel have also been addressed in much greater depth in another consultant study[17]. As those issues were not the major focus of this study, we will not discuss them further in this report.

3.4.1 Restricting Further Import of Vehicles with Two-Stroke Engines

The number of two and three-wheelers in use has been increasing rapidly. More than 500,000 motorcycles and 100,000 three-wheel vehicles have been registered, and the numbers are increasing by about 40,000 and 11,000 per year, respectively. A large fraction of the motorcycles and nearly all of the three-wheelers are equipped with two-stroke petrol engines having very high pollutant emissions. The design of the two-stroke engine causes as much as one-third of the fuel it uses to pass unburned into the exhaust, making these engines by far the largest source of toxic hydrocarbon emissions[18]. This problem is exacerbated by the petrol composition, which includes 3 to 4% benzene by volume[17]. At the same time, the requirement that lubricating oil be mixed with the fuel means that significant amounts of oil particles are emitted as well, contributing to the high levels of PM10 pollution in Colombo and other cities. A small number of three-wheelers are equipped with diesel engines, which also emit extremely high amounts of particulate pollution.

A World Bank study in Bangladesh[19] has developed some data on PM emissions from two-stroke three-wheelers. A seven-year-old vehicle using 8% straight mineral oil in the fuel emitted 2.7 grams of PM per kilometer. Using an oil specially formulated for two-stroke engines, at the recommended 3% concentration, the emissions were 0.9 g/km. A newer, four-

year old engine designed to meet stricter emission standards emitted 0.6 and 0.2 g/km on mineral oil and two-stroke oil, respectively. For comparison, average PM emissions from a representative selection of diesel dual-use vehicles tested in Bangkok (from a fleet very similar to that in Sri Lanka) were about 0.4 grams per kilometer.

Due partly to the use of catalytic converters, HC emissions from new Indian three-wheelers at present are about half those of the four-year-old three-wheeler tested in the World Bank program, and it is likely that the PM emissions have also been reduced by about half. If so, this would still leave PM emissions from a new three-wheeler at around 0.1 g/km using the correct oil, and as much as 0.3 g/km using straight mineral oil – i.e. as much as three times the PM emissions permitted from a diesel motor car meeting Euro 2 standards. Since catalytic converters on two-stroke engines tend to have very short useful lives, average in-use PM emissions will probably be much higher than this.

The worldwide motor industry is seeing an increasing replacement of two-stroke engines by four-strokes. Although somewhat more costly to build, these engines typically use 20 to 33% less fuel, so that the initial costs are more than repaid by fuel cost savings over the vehicle's life. The difference in fuel economy is essentially due to eliminating the loss of unburned fuel into the exhaust. Particulate and hydrocarbon emissions from four-stroke engines are typically 90% less than from two-stroke engines. New emission standards in major motorcycle-producing countries such as Taiwan, Thailand, and India have resulted in four-strokes capturing a large share of the market. Although some two-stroke engines have also met these emission standards with the use of catalytic converters, experience in Taiwan has shown that durability of these catalysts is poor. The high pollutant concentrations in the exhaust result in very high temperatures in the catalyst, causing the catalytic materials to lose surface area and efficiency.

More than 95% of three-wheelers sold in Sri Lanka are produced by one Indian company, Bajaj, and distributed in Sri Lanka by David Pieris Motor Company Ltd. (DPMC). Bajaj produces and sells both two-stroke and four-stroke versions of its three-wheeler product in India, subject to the strict Indian emission standards. According to DPMC, the two-stroke version of the Bajaj three-wheeler is equipped with a catalytic converter, and DPMC have stated that new Bajaj three-wheelers imported to Sri Lanka will be equipped with these catalytic converters as well[20]. Although three-wheelers with four-stroke engines are also available from DPMC, the price is about RS 50,000 higher than for a two-stroke engine, which has discouraged their purchase.

The large increase in price for a four-stroke engine is difficult to explain. According to the World Bank study, the ex-showroom price difference between Bajaj two-stroke and four-stroke three-wheelers in Delhi was about US$88, or the equivalent of 8,300 Sri Lankan rupees. This difference is also consistent with earlier estimates by EF&EE[18] of the manufacturing cost difference between two-stroke and four-stroke engines, which came to around US$20 to US$40. The relatively high incremental cost charged by DPMC may thus reflect the premium for what is perceived as a "quality" option. Such options typically carry rates of manufacturer's and dealer's profit several times higher than those for the basic vehicle.

If four-stroke engines were mandatory, rather than optional, the price increase needed to cover the incremental manufacturing costs would likely be closer to Rs 10,000 than the present Rs 50,000. As Table 3.9 shows, this difference could be recovered in about one year through the fuel cost savings due to the four-stroke engine. In addition to fuel, the vehicle owner would save the expense of two-stroke oil and the trouble of mixing it, and would likely experience a reduction in maintenance costs (four strokes require more expensive maintenance, but far less often).

Table 3.9: Annual fuel consumption and costs for two-stroke and four-stroke three-wheelers

	2-Stroke	4-Stroke	Units
Fuel Economy	26	31	km/liter
Annual Travel	30,000	30,000	km
Annual Fuel Use	1,154	984	liter
Annual Fuel Cost	57,692	49,180	Rs
Annual Saving		8,512	Rs

If allowed to continue, the rapid expansion of the two-stroke vehicle fleet in Sri Lanka will inevitably degrade air quality. Limiting new vehicle imports to four-stroke engines only would greatly reduce this degradation, buying time for more comprehensive emission standards to come into effect. At the same time, it would result in little or no disruption of the market, since motorcycles and three-wheelers equipped with four-stroke engines are readily available.

One alternative to a complete ban would be to allow the importation of two-stroke engines equipped with catalytic converters, as long as these meet Indian or other advanced emission standards. However, this would result in higher costs to the vehicle owner in the long term, because of the higher fuel consumption. Furthermore, the catalytic converters would need to be replaced at least once per year to maintain their effectiveness, and could easily be poisoned by the owner using crankcase oil instead of an appropriate two-stroke oil. Inspection and enforcement programs would have to be set up to assure that these replacements are made, and the replacement costs (probably at least USD 25) would have to be borne by the owner. The result would be higher costs to the owner and to Sri Lankan society. PM emissions under this option would still be significantly higher than with four-stroke engines.

For these reasons, we recommend that the Government consider adopting a policy restricting the further import of road vehicles of any description that are equipped with two-stroke petrol or LPG engines. This policy should take effect as quickly as practicable. Exceptions could be made for two-stroke engines that are demonstrated by independent testing to have PM emissions comparable to those of emission-compliant four-stroke engines used in similar vehicles. At the same time, to avoid shifting from one polluting vehicle type to another, we recommend that the Government also prohibit the further import of motorcycles and three-wheelers equipped with diesel engines.

3.4.2 Restricting Further Import of Light-Duty Diesel Vehicles

Fuel tax policy in Sri Lanka, as in Europe, has long favored diesel fuel with relatively low taxes compared to petrol. Used vehicle import policy also favors importation of "dual-purpose" vehicles such as vans and pickups over importation of passenger cars. The favoritism toward diesel engines and commercial vehicles was originally intended to benefit the poor, by reducing costs for agriculture, truck transport, and mass transit; at the expense of private cars. Unfortunately, the economic incentives so created – together with technological developments in light-duty diesel engines - have resulted in the introduction of large numbers of light-duty trucks and vans equipped with diesel engines. These vehicles are able to take advantage of the lower tax on diesel fuel, thus avoiding the higher road use taxes that are intended to apply to these less-essential uses.

Light-duty diesel engines tend to have higher initial costs and higher maintenance costs than petrol engines, but consume less fuel. They also exhibit far higher pollutant emissions – especially of particulate matter, which constitutes the primary threat to public health from air pollution in Colombo. These emissions are compounded by the typically poor maintenance experienced by these light-duty engines. The results are visible on every street in Colombo, with a large fraction of the light-duty diesel vehicles belching grossly excessive volumes of smoke.

Detailed analysis by another consultant as part of the fiscal policy study[21] showed that the existing preference for light-duty diesel vans and pickups is largely an unintended result of the Government's tax and vehicle import policies. In the absence of fuel and vehicle taxes, the fiscal policy study concluded that most buyers would prefer petrol motorcars, whereas the choice between diesel and petrol dual-purpose vehicles would be nearly even. The choice of diesel instead of petrol engines in dual-purpose vehicles imposes large external costs on society. If diesel fuel were to be taxed so as to "internalize" the external costs of premature death and illness due to diesel particulate emissions, the fiscal policy study concluded that buyers of dual-purpose vehicles would overwhelmingly opt for petrol engines.

The main reason for the popularity of dual-purpose vehicles over motorcars is that used dual-purpose vehicles up to five years old are allowed to be imported, whereas used motorcars can only be imported up to three years old. The older vehicles are appraised at lower values, and thus pay lower *ad valorem* import tax. In addition, the rate of import tax is lower on vehicles for the carriage of goods (including dual-purpose vehicles).

Since existing tax and vehicle import policies are unintentionally creating incentives to pollute more, the "first best" policy would be to revise the fuel tax differential and vehicle import policies, preferably in such a way as to reflect the high social costs imposed by diesel pollution. The necessary large changes in the fuel tax differential may not be immediately feasible. However, a change in vehicle import policy could be implemented – either to prohibit the import of light-duty diesel vehicles less than 3.5 tons, or to restrict these to new vehicle imports only (while continuing to allow the import of used petrol vehicles). Since petrol vehicles in this size range are readily available, such a policy would have little impact on used vehicle sales, but the vehicles imported and sold would have far lower emissions than

under present policies. Enforcement of emission standards for new vehicles is much easier than for vehicles imported used.

A number of governments have adopted similar policies for light-duty diesel vehicles. In Mexico, for instance, administrative guidance during the 1990s strongly discouraged light-duty diesel vehicles, and none were sold. Brazil has adopted particulate emission standards of 0.05 g/km for light-duty diesel vehicles. These are so strict as to effectively prohibit their sale. Recent U.S. and California emission standards also strongly discourage light-duty diesel vehicles less than 8,500 pounds gross weight (or about 3.9 metric tons). Vehicles over about 3.5 to 4.0 tons are considered "heavy duty". There is presently no practical alternative to the diesel engine for most vehicles in this size range.

It could be argued that light-duty diesel vehicles emit less CO_2 than petrol vehicles, and might be desirable for that reason. In future, these vehicles may also be equipped with filters that virtually eliminate their particulate emissions (a few models so equipped are already sold in Europe, but many filter designs require low-sulfur fuel). A light-duty diesel vehicle equipped with a sulfur-tolerant particulate filter would have similar emissions to well-controlled petrol vehicle, and would therefore be acceptable from an air quality standpoint.

We recommend that the Government move immediately to restrict the importation of light-duty diesel vehicles under 3.5 tons. To avoid shutting the door on future advanced technologies, an exception should be made for vehicles equipped (and emission certified in the country of origin) with a diesel particulate filter that achieves at least 80% reduction in particulate emissions, and that is capable of tolerating the sulfur levels found in Sri Lankan fuel.

3.4.3 Gaseous Fuels

In a discussion with Environment Minister Bandaranaike during the Inception Mission, the Minister expressed interest in the use of buses and three-wheelers fueled by gas. This approach is being used successfully in Delhi, Beijing, and Cairo, and – in the long term – holds considerable promise for reducing particulate emissions from heavy-duty vehicles in Sri Lanka. However, a number of problems will prevent its implementation in the immediate future.

The gaseous fuel being used in both Delhi and Cairo is natural gas, which is primarily methane. Natural gas is not presently available in Sri Lanka, but may become available in the future due – e.g. – to the importation of liquefied natural gas as fuel for power plants. Because of its combustion characteristics, natural gas is a good fuel for heavy-duty engines. The "gas" that is now available in Sri Lanka is liquefied petroleum gas or LPG. This fuel makes a good substitute for petrol in light-duty engines, but it is less suitable for heavy-duty applications.

In Delhi, compressed natural gas (CNG) is being used both in buses and in three-wheelers. In both cases, the greatest success has been with new vehicles designed for CNG from the start. Both Tata and Ashok-Leyland now offer CNG bus chassis, while Bajaj offer a four-stroke, CNG version of their rear-engine three-wheeler taxi. All of these have been successful. In contrast, the conversion of existing diesel buses to natural gas has presented many problems. Many of the conversion systems used are poorly designed, and some are manifestly unsafe[22].

The companies offering these conversions are in many cases fly-by-night operations that are unable to stand behind their products. We do not recommend the conversion of existing buses in Sri Lanka to natural gas.

It is possible to convert existing three-wheelers equipped with two-stroke or four-stroke petrol engines to use natural gas or LPG fuel. The "tuk-tuks" in Bangkok, for instance, run primarily on LPG. However, this change is not necessarily beneficial for emissions. In the case of two-stroke engines, the particulate emissions derive from the lubricating oil, and thus will not be affected by changing the fuel. Indeed, particulate emissions may well increase, since the gaseous fuel cannot be mixed with lubricating oil, making it necessary to install a separate oil feeding mechanism (conversely, an appropriately-designed oil feeding mechanism could reduce lubricating oil consumption and thus PM emissions). Although use of gaseous fuels does result in a change to less-toxic hydrocarbons in the exhaust, this benefit is relatively minor, compared to the substantial costs and safety risks involved in retrofitting existing vehicles to use these fuels.

The use of natural gas in place of diesel as a fuel for heavy-duty vehicles has many advantages, of which the most significant are extremely low emissions of particulate matter and SO_2, and the ability to achieve lower emissions of NOx with appropriate engine design[23]. However, the costs of supplying natural gas solely for vehicles would likely be prohibitive compared to other technologies such as ultra-low sulfur diesel with particulate filters and other advanced emission controls. In the event that natural gas were to be discovered in Sri Lanka, or that it were to be imported on a large scale (and thus at low cost) for other purposes such as power generation, then it would make good sense to consider it as a fuel for urban buses and trucks at the same time.

3.5. DESIGN OF A VEHICLE INSPECTION AND MAINTENANCE PROGRAM

The past few decades have demonstrated the importance - and also the difficulty - of implementing emission control measures for vehicles already in use. Such measures are an essential complement to emission standards for new vehicles. Although difficult to implement, an effective inspection and maintenance (I/M) program can significantly reduce emissions from uncontrolled vehicles.

I/M programs are also needed to ensure that the benefits of new-vehicle control technologies are not lost through poor maintenance and tampering with emission controls. When I/M programs identify non-complying vehicles, this information can be fed back to new-vehicle regulatory programs, allowing regulatory authorities to focus investigations and test orders on vehicles with consistently high emissions. Inspection and maintenance programs help identify equipment defects and failures covered by vehicle warranty schemes. The programs also discourage tampering with emission controls or misfueling; the threat of failing inspection is considered a strong deterrent. Without effective I/M programs, compliance with new vehicle emission standards is significantly weakened.

3.5.1 What Works? Worldwide Experience

Especially in developing countries, care is necessary in designing the inspection, enforcement, and mechanisms for I/M programs. Otherwise, weak administrative and regulatory arrangements can result in massive evasion of I/M programs or corrupt practices on the part of I/M officials and inspectors. The experience with enforcement of traffic and safety regulations in developing countries has shown many instances of these types of problems.

Two types of I/M programs are common: centralized programs, in which all inspections are done in high-volume test facilities operated by the government or by a private government contractor, and decentralized programs, in which both emissions testing and repairs are done in private garages. The decentralized arrangement is much less effective because of fraud and improper inspections. Centralized programs operated by private contractors generally yield the best results, and it is recommended that Sri Lanka adopt this type of inspection program.

Based on experience in other developing countries, as well as the U.S., we recommend that compliance with in-use vehicle emission limits be verified and enforced through a combination of periodic inspections in centralized test facilities and on-road checks by the traffic police, with the actual testing performed by specialized technicians. We recommend that the inspection facilities be constructed and operated by private capital, with at least two or three different operators. Technical supervision and oversight of these inspection facilities should be provided by a separate, highly-qualified technical organization. The costs of this supervision, like the costs of the inspection itself, should be paid by the vehicle owners through an inspection fee. The supervising

organization should also be responsible for providing technicians and equipment to support the Police in on-road enforcement, for periodic review and adjustment of the emission standards, and for public reporting of the results.

3.5.1.1 Inspection Facilities

Periodic inspection and maintenance programs can be classified as either *centralized* or *decentralized*. In centralized programs, vehicles are required to be presented at one of a small number of high-volume inspection facilities for inspection. These facilities are government-controlled, and may be run either by government employees or by an independent contractor (the latter arrangement is more common, due to its generally lower costs). In the typical program, government franchises a single contractor to build and operate all of the inspection centers in given area, while charging a set fee to the public. These franchises are normally awarded on a competitive basis, taking into account both the technical competence and experience of the proponents and the proposed fee. The fee is normally set at a level that allows the I/M contractor to recover its capital and operating costs and make a profit over the time period covered by the franchise.

In some cases, governments have issued multiple franchises for the same area - in Mexico City, for instance. In other cases, a single metropolitan area has been divided into multiple zones, with a single contractor in each zone. An approach that results in multiple I/M contractors is strongly to be recommended, as it reduces the program's dependence on any one contractor, and makes it possible to revoke the franchise of an incompetent or dishonest contractor without destroying the entire program. Close oversight is needed to ensure that contractors do not compete with each other for customers by offering false passes.

In a decentralized program, vehicles are inspected at any of a large number of private service stations and garages, which also make repairs on vehicles found to fail the emissions test. These inspection and repair stations are generally licensed and authorized by the regional or local government, but are not under its direct control. This situation presents many opportunities for fraud, both against the consumer (failing vehicles which should have passed, in order to "repair' them) and against the system (passing vehicles which should have failed, either in return for a bribe or just to keep the customer happy). To help deter fraud, decentralized I/M programs in the U.S. require the use of emissions analyzers such as the BAR 90*, which incorporate extensive automation of the inspection process. This automation is intended to make fraud more difficult. In addition, well-run decentralized programs incorporate extensive overt and covert (undercover) audits of inspection stations to make fraud more risky. Fraud and poor performance are, nonetheless, still very possible, and common. Although the BAR 90 analyzer itself reads the pollutant concentrations and makes the pass-fail decision, there is no way to ensure that the analyzer is inserted in the right tailpipe. Similarly, there is no way for the analyzer to know

* Specifications for the BAR 90 analyzer were developed by the California Bureau of Automotive Repair (BAR) to support that state's Smog Check Program. They have since been widely copied. Use of analyzers meeting this specification became mandatory in California in 1990. Because of their extensive automation, data recording, and other features, these analyzers are fairly expensive - costing about US$12,000 compared to less than US$5,000 for a simple HC and CO measurement system

whether the mechanic has carried out the visual and functional checks he has been prompted to perform, and many mechanics do not do so in order to save time.

Although it is undoubtedly true that many - perhaps the majority - of private garages doing inspection in decentralized programs are competent and conscientious, there is a tendency for the bad inspectors to drive out the good, in a process similar to Gresham's law. Inspectors who can manage to pass vehicles that should fail will tend to be patronized by consumers wishing to avoid an expensive repair, in preference to their honest competitors. Inspectors who don't take the time to do a full underhood inspection can carry out an inspection in less time, and therefore at lower cost, than their more conscientious competitors. Even though the majority of inspectors might be honest and competent, the owners of the high-emitting vehicles that are the target of the inspection program are disproportionately likely to patronize the minority who are not – thus greatly reducing the effectiveness of the program. Studies by U.S. EPA auditors of decentralized programs in the U.S. have often found rates of improper inspections exceeding 50%. Experience with decentralized I/M in Mexico showed extremely high rates of fraudulent inspections, leading the Mexican authorities to abandon that approach in favor of a centralized system.

Since the number of inspection locations and inspectors is much smaller in a centralized program, the levels of skill and training of the inspectors can be much higher, and cheating can be prevented much more easily. Centralized I/M programs thus tend to have much lower rates of improper inspections. They are also better suited for handling retests after repair, and for determining eligibility for cost waivers if these are permitted. In decentralized programs, where the same garage performs both the repair and the after-repair check, these activities present a clear and important conflict of interest.

Inspection costs tend to be lower in centralized facilities due to economies of scale. In California's former decentralized idle/2500 RPM I/M program, inspection fees averaged about US$ 40. Costs of I/M 240 testing in centralized facilities range from US$ 10 to US$22, and the nine former centralized contractor-run programs (using idle/2500 RPM tests) in the United States averaged less than US$ 8 per inspection. The three former centralized programs in Connecticut, Wisconsin and Arizona utilizing dynamometers and loaded test procedures charged fees in the range of US$ 7.50 to US$ 10. Fees in the current Mexican program are similar.

The institutional setting also affects the type of test procedures possible. Simple measurements such as HC and CO concentrations at idle can be made with garage-type analyzers. More sophisticated and costly dynamometer testing is required to identify malfunctioning emission controls on new-technology vehicles reliably. Due to the cost of the equipment, centralized facilities are the only practical solution for sophisticated, dynamometer-based testing such as the I/M 240.

A key reason for the better economic performance of centralized, high-volume I/M programs is the better utilization of equipment and trained personnel that these make possible. A well-run centralized I/M facility can be expected to inspect between 10,000 and 25,000 vehicles per lane per year. In comparison, it would be rare for private garages in a decentralized program to inspect more than about 2,000 vehicles per year, on average.

EF&EE recommends that vehicle inspections in Sri Lanka be carried out in centralized, high-volume, test-only facilities. As soon as possible, these should be linked by electronic com-

munications to a central database. This arrangement would help to minimize the potential for corruption in the testing process. Close links should also be established between the vehicle registration process and the emissions testing, in order to avoid the potential for counterfeiting of vehicle inspection certificates or stickers. It is recommended that these inspection facilities be operated by a small number of private inspection contractors (preferably more than one), with the role of Government limited to overseeing the contractors' performance. The Government should have authority to impose fines and other sanctions for improper or corrupt behavior, including the possibility to rescind the authorization to perform inspections in severe cases. A contractor who allowed corrupt practices in the inspection program would thus run a serious risk. Contractors would have a strong incentive to establish pay, management, and supervision practices that minimize this possibility. Because of the rigidity of government personnel procedures, preventing corruption may be much more difficult where the government itself operates the inspection facility.

3.5.1.2 On-Road Enforcement

Roadside or on-road vehicle inspection programs provide an important supplement to periodic inspection and maintenance. Periodic inspection is predictably scheduled, giving vehicle owners an opportunity to evade the program. For instance, one common cause of high smoke emissions in diesel engines is tampering with the maximum fuel setting on the fuel injection pump. This provides more fuel to the engine, increasing power output and smoke. Since owners know when the vehicle will be inspected, they can adjust the pump to its proper setting immediately before the inspection, then return it to the higher power setting afterward. Another way of reducing visible smoke is putting a handful of gravel in the exhaust pipe just before the inspection. Similar tricks are possible, and reportedly common, for meeting carbon monoxide emissions standards with gasoline vehicles.

Since a vehicle owner cannot predict whether he will be targeted by an on-road or roadside inpection, such inspections are difficult to defeat. On-road and roadside inspections are especially useful for enforcing vehicle smoke limits, since the visible nature of smoke emissions allows enforcement efforts to target the worst offenders. This reduces the costs and increases the effectiveness of the program, and minimizes inconvenience to owners of vehicles that are not polluting excessively.

A roadside smoke inspection program has been implemented in California to control smoke emissions from heavy trucks. Smoke inspection teams are deployed at weight and safety inspection stations and at other roadside locations. A member of the inspection team observes oncoming trucks visually, waving over those producing excessive smoke. These are then subjected to a free-acceleration smoke test using a smoke opacity meter. Vehicles that pass are sent on their way; those that fail receive a citation that can be cleared only after the vehicle is repaired. A second citation during the same year carries a much larger fine and requires the vehicle be presented at a smoke test location for smoke measurement after repairs.

Roadside checks for smoke opacity are also appropriate for control of excess white smoke emissions from gasoline vehicles, including two-stroke motorcycles and three-wheelers. These emissions are believed to result, in many cases, from using too much or the wrong type of

lubricating oil. Such practices are more likely to be detected by visual screening on the road than by a periodic I/M test.

Roadside checks for hydrocarbon and carbon monoxide emissions from gasoline vehicles have also been implemented in a number of countries, including Mexico (subsequently abandoned) and Thailand. Since vehicles with high hydrocarbon and carbon monoxide emissions are not usually as obvious as those producing excessive smoke, these programs must rely on stopping vehicles at random. This reduces the efficiency of the program and increases the inconvenience to drivers of low-emitting vehicles. With the recent development of practical remote sensing systems for vehicle emissions, the potential exists for these roadside programs to be targeted more effectively. It would be difficult to justify such expensive and sophisticated measures in Sri Lanka, however, since the available data do not indicate that HC and CO emissions are a major problem.

3.5.1.3 Quality Assurance and Oversight

In order for an I/M program to be effective, it is necessary that arrangements be put in place to assure that the inspectors are properly equipped and trained to perform accurate inspections according to well-defined procedures, and that controls be established to ensure that inspections actually are performed and reported accurately and repeatably. In our view, the most important near-term QA/QC requirements are the following:

1. establishment of standard written procedures for vehicle inspection, for assessing whether vehicles pass or fail the inspection, and for reporting the results;
2. training vehicle inspectors to apply the standard inspection procedures in a consistent, repeatable manner;
3. establishing a system of inspection document control based on serially-numbered, counterfeit-resistant inspection certificates;
4. establishing and implementing written procedures for routine reporting of all inspection results for verification purposes and for statistical analysis.

During program operation over the longer term, the main QA/QC requirements will be the following:

1. frequent audits of inspection station equipment, training, procedures, and document control by uniformed inspectors (overt audits). These audits should be designed to assure that I/M testing is performed consistently and repeatably from station to station and inspection to inspection, that calibration standards are accurate and consistent, that proper control is maintained of inspection stickers, and that data are properly reported to the central database;
2. verification of inspection certificates submitted by vehicle owners against reported results from the inspection station;
3. routine analysis of reported results from each inspection station to identify suspicious patterns of activity; and

4. undercover (covert) audits of inspection stations to detect fraudulent testing and to gather evidence for prosecution. These audits generally involve enforcement staff in civilian clothes bringing specially-prepared vehicles in to be inspected.

In many countries, firms engaged in activities that could affect public safety or the environment are required, as a condition of being allowed to operate, to pay for and undergo inspection or certification by an independent organization. Examples of such independent inspection firms include the American Bureau of Shipping, Det Norske Veritas, and the German TÜV, among others. In this way, the public is protected, and the costs of inspection are borne by the users of the service rather than the taxpayers. A similar approach has also been applied to QA and QC for vehicle inspection programs. For example, the California Bureau of Automotive Repair finances its entire budget by charging inspection stations for the inspection certificate forms. The same approach could be used to finance private-sector oversight of the vehicle inspection program in Sri Lanka.

In one approach to a privatized QA/QC program, the Government would award, by public bidding or directly to a selected non-profit institution, the exclusive right to sell the serial-numbered, counterfeit-resistant windshield stickers issued to vehicles that pass the inspection. Bidders for this right would have to agree, as a condition of the contract, to carry out the complete QA/QC program, including specified numbers of overt and covert audits, setting up and operating the computer system for data entry and analysis, and so forth. I/M inspection stations would purchase the number of stickers they required for their customers, and would recover the costs as part of their inspection fees. Each bidder would propose the price it would charge per certificate to carry out the QA program. The winning bidder would be the one offering the best combination of a superior technical proposal and low cost. Of course, it would be necessary to increase the allowable fees for the inspection to allow the inspection stations to recover the costs of the stickers.

An alternative arrangement is also possible, in which Government itself would sell the windshield stickers to the I/M inspection stations, placing the resulting revenue in a special fund for I/M enforcement. Monies from this fund could then be used to pay a private or NGO contractor to provide I/M technical support, and to defray Government's own costs for I/M program supervision and oversight. This approach might be more acceptable from a political standpoint.

Privatizing the QA/QC aspects of the I/M program to the greatest extent possible would avoid the long lead-times and institutional rigidity associated with Government budgeting and personnel allocation, and would thus allow an expanded QA/QC program to take effect much earlier than would otherwise be possible. The greater flexibility of private-sector organizations would also help to reduce the overall costs, while the allocation of these costs to the vehicle owner instead of taxpayers in general would be desirable to ensure that "the polluter pays".

3.5.2 Assessment of the Vehicle Village Concept

The Vehicle Village concept is outlined in a project proposal document prepared by the Department of Motor Traffic[13]. This proposal was developed as a way to improve customer service and reduce the incidence of fraud in the vehicle registration and inspection process. Efforts to implement it are being supported in part by German Technical Cooperation (GTZ).

The idea is to develop a "Vehicle Village", where all of the requirements for vehicle inspection and registration could be attended to at one time, thus saving time and inconvenience for vehicle owners. At the same time, the Village would include modern technology for vehicle inspection and driving tests, in collaboration with the private sector. The vehicle registration system would be redesigned with new technologies to make it more user-friendly and fraud-resistant.

While the vehicle-village concept, as outlined, contains little detail, the general ideas of bringing together the different inspection and registration programs in a single process; and employing up-to-date technology to improve service and reduce fraud are strongly to be recommended. So, in our opinion, is the focus on making use of the private sector wherever practical. The Vehicle Village concept could readily accommodate the type of inspection and maintenance programs recommended in the preceding section.

The following is one example of how a "Vehicle Village" might be combined with an appropriate I/M program.

- Each "village" would include one or more vehicle inspection facilities, each of which would be privately owned and operated, under a contract with the Government. These inspection facilities could perform dynamometer emission tests as appropriate for each type of vehicle, and could also be expanded to include basic safety checks such as brakes, lights, glass, etc.
- An independent quality-assurance contractor would provide technical support to Government in overseeing the operation of the inspection stations. This would include establishing and maintaining a central database of vehicle information (including inspection results and registration status). It would also include quality-assurance checks on the inspection facilities: overt (announced) inspections, checking the calibrations of emission analyzers, statistical analysis of the inspection results to identify any anomalies or suspicious patterns, covert inspections by inspectors in plain clothes, and the use of undercover vehicles.
- Vehicles that passed the inspection and paid all of their fees would be issued a counterfeit-resistance windshield sticker (like the holographic stickers used in Mexico City) showing the year and month until which the vehicle was permitted to operate before re-registering.
- Vehicles that failed the inspection would not be permitted to register, but would have to undergo repairs and retake the inspection. To avoid creating a conflict of interest, the vehicle inspection facilities would not be permitted to offer repairs, but would provide the owners of failing vehicles with a list of "qualified" garages having appropriate equipment and appropriately trained personnel. This list would be compiled by the quality-assurance contractor, and would be the same for all facilities (i.e. facilities would not be permitted to steer motorists to a favored repair shop).
- Persons seeking to renew their vehicle registrations would bring their vehicles to the inspection facility of their choice. The facilities would each charge the same fee for a given type of vehicle, and these fees would be established in the Government contracts. The facilities would therefore be unable to compete on price, but would be encouraged to

compete for customers by offering better service, fixed appointment times, convenient operating hours, etc.

- Together with the inspection fee, the motorists would also pay a surcharge to cover the costs of providing an independent quality assurance contractor. At the same time, they would also pay their annual vehicle registration taxes, and any outstanding traffic fines. Collection and disbursement of these fees could be done by the vehicle inspection contractors themselves, or by a financial institution such as a Bank, which would establish a payment counter at the inspection facility. The amounts collected would be tracked through the same database that tracked the registration status.

Both privately owned and commercial vehicles could benefit from the establishment of such vehicle villages. However, mixing private cars and motorcycles with large numbers of heavy trucks and buses would not be recommendable. Instead, we recommend establishing separate vehicle villages for light-duty and heavy-duty vehicles. This would reduce people's exposure to smoke and noise, as well as the safety hazard of heavy vehicles maneuvering in a crowded area.

3.5.3 I/M Test Procedures For Diesel Vehicles

Diesel vehicles emit relatively large amounts of NOx, PM2.5, HC, and SO_2, but little CO. Of the principal diesel emissions, the amount of SO_2 emitted is controlled by the sulfur content of the fuel, while the NOx emissions are determined primarily by the engine design. Experience has shown that diesel NOx emissions are not likely to increase significantly due to engine wear or poor maintenance, and that there is little that the vehicle owner can do to reduce these emissions. There is thus little point in testing for these emissions. On the other hand, PM2.5 and HC emissions can increase greatly as a result of poor maintenance, engine wear, and/or tampering with the maximum power setting of the engine, and all of these are under the control of the vehicle owner. By identifying and requiring the repair of those vehicles that are producing excess emissions, an I/M program can reduce average HC and PM2.5 emissions from diesel vehicles.

Diesel HC and particulate emissions are difficult to measure directly – requiring special measures to prevent the HC from condensing, and to dilute, filter, and weigh the PM. Fortunately, diesel engine problems that result in high HC and PM emissions also tend to increase smoke. Many of the diesel trucks and buses in use in Sri Lanka exhibit grossly excessive emissions of black smoke.

When properly designed, calibrated, and maintained, diesel engines emit little or no visible smoke, and their total particulate emissions are relatively low - less than 1 gram per kilometer. Although large amounts of soot are formed during the combustion process, the presence of sufficient air in the cylinder and good air-fuel mixing allows nearly all of the soot formed to be burned out before it is emitted from the engine. Where poor mixing or overfueling interfere with the process of soot combustion, however, smoke and particulate emissions can increase enormously.

Grossly excessive smoke emissions are generally found to result either from improper calibration of the fuel injection pump - allowing excessive fuel into the cylinder - or from

problems in the fuel injection system that interfere with proper air-fuel mixing. Dirty air filters or other problems that restrict airflow to the engine can also cause high smoke emissions. Improper calibration is usually the result of tampering with the fuel injection system - "turning up" the amount of fuel injected to increase the engine power output. In naturally-aspirated diesel engines like most of those used in Sri Lanka, this type of tampering results in grossly excessive smoke emissions at full power. From our field observations, this type of tampering appears to be very common among diesel vehicles in Sri Lanka. Dirty air filters, worn-out fuel injectors, and fuel injectors with severe fuel-related deposits may also be responsible for many of the numerous cases of excessive smoke emissions observed.

3.5.3.1 Smoke Measurement Principles

Smoke can be measured in a number of ways, including the Bosch method, Hartridge and similar partial-flow opacity meters, or with the use of a full-flow opacity meter. The characteristics of each type of meter and its advantages and disadvantages are discussed here.

In the Bosch method of smoke measurement, a spring-loaded sampler pulls a fixed volume of smoke through a filter paper, depositing the smoke particles on the paper. The filter paper is then "read" by a photoelectric device, which produces a "Bosch Number" corresponding to the degree of blackness of the collected particulate matter. The higher the Bosch number, the darker the smoke. This method provides an accurate measure of soot and other dark material in the smoke, but it responds poorly or not at all to smoke particles that are not black. Lubricating oil and diesel fuel droplets, for instance, produce a bluish or grayish smoke (due to light scattering), but have little color in themselves. When collected on the Bosch filter, these droplets tend to make the filter wet, but not black, and therefore are not detected by the Bosch method. For I/M purposes, this is a major drawback, since excessive oil smoke (due to poor mechanical condition of the engine) is a major contributor to total particulate emissions from diesel vehicles in use, especially in developing countries. Because it fails to detect this blue or gray smoke, the Bosch method correlates poorly with actual particulate emissions from in-use vehicles[24].

For purposes of inspection and maintenance, a better measure of excessive particulate emissions is given by a light-transmission opacity meter (opacimeter). This type of smoke meter measures the attenuation of a beam of light shining through the smoke plume, and registers typically in percent opacity. Zero percent opacity corresponds to no smoke, while 100% opacity allows no light transmission. Since these opacimetric measurements include both the effects of light absorption (by soot) and light scattering (by oil or fuel droplets), they provide a better indicator of excessive emissions of either type of smoke.

Light-transmission opacity meters include full-flow meters, which measure light absorbtion by the smoke plume at the end of the exhaust pipe. They also include partial-flow, sampling meters such as the Hartridge-type smokemeters commonly used in Europe. The Hartridge and other partial-flow meters draw a continuous sample of the exhaust into a chamber, and measure the attenuation of a beam of light shining through the chamber.

For light-transmission opacity meters, the opacity measurement depends on the density of the smoke and the width of the plume of smoke that the light beam must pass through. This width is

known as the path length. The path length is related to the light attenuation in the following equation, called the Beer-Lambert law:

$$N = 100(1 - e^{-kL})$$

where N is the opacity, in percent, e is the base of the natural logarithms, k is the absorption coefficient (smoke density), and L is the effective path length through the smoke, in meters. This equation can be used to correct smoke opacity measurements made at differing path lengths to a single comparable basis. This relationship applies both to full-flow and partial-flow opacity meters. For the full-flow meter, the path length can usually be approximated as the diameter of the exhaust pipe, which is typically in the range from 50 to 150 mm. For partial-flow meters, it is the length of the measuring chamber built into the instrument. This length varies depending on the meter: for Hartridge-type meters, it is 457 mm (18 inches). This relatively long path length makes the Hartridge meter sensitive to relatively low levels of smoke, but impairs its ability to distinguish between moderate and extreme smoke levels.

Although correlations are published which relate Bosch and other indices to opacity, the relations between the Bosch and opacimetric determinations are valid only for "normal" (sooty) smoke, and only under steady-state conditions. Figure 3.2 shows the relationship between Bosch, Hartridge, and full-flow smoke opacity established for these limited circumstances. This relationship is not valid for smoke containing a significant amount of oil or other hydrocarbons, nor is it valid for measurement under transient conditions, such as the free-acceleration test procedure discussed below.

Measured smoke opacity varies with the length of the light path, and therefore with the type of instrument. This is a common source of confusion. For example, European regulations often use the word "opacity" when what is meant is "opacity as measured by a Hartridge-type smokemeter, with a path length of 457 mm". On the other hand, when U.S. regulations specify "opacity" they mean "opacity as measured by a full-flow smokemeter, with the path length equal to an exhaust pipe diameter of 2, 3, 4, or 5 inches depending on the power rating of the diesel engine in question. For the same smoke density "K", these measures give very different opacity values, as Figure 3 shows.

Since the smoke density or "K" value does not vary with the instrument type or path length, it is most convenient to express regulatory smoke limits in terms of this value rather than opacity. To convert smoke data from opacity values in percent to "K" values, it is only necessary to rearrange the Beer-Lambert equation as follows:

$$K = \frac{-100}{L} \ln\left(1 - \frac{N}{100}\right)$$

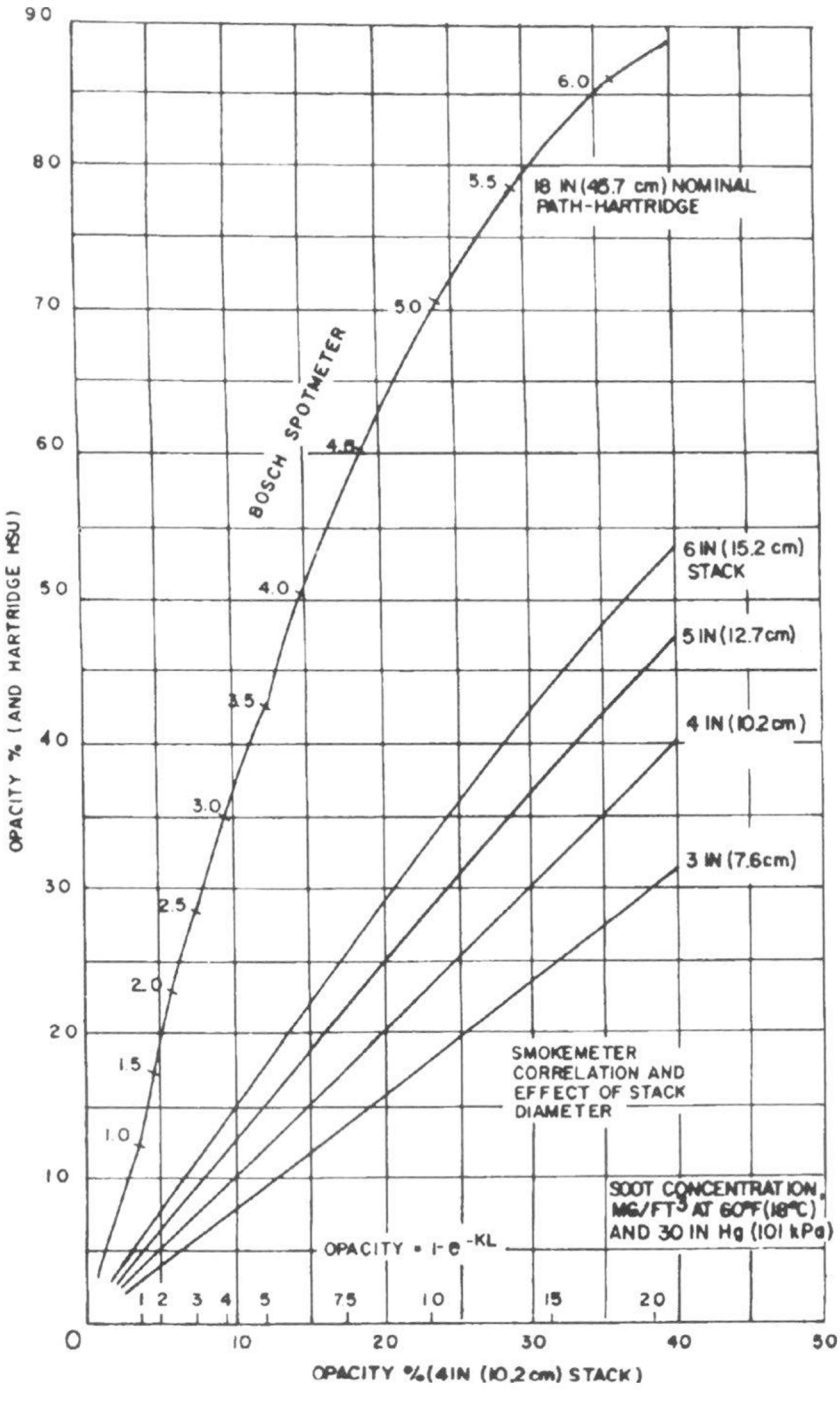


Figure 3.2: Correlation between different diesel smoke measurement indices (valid for steady-state, black smoke emissions only)[25]

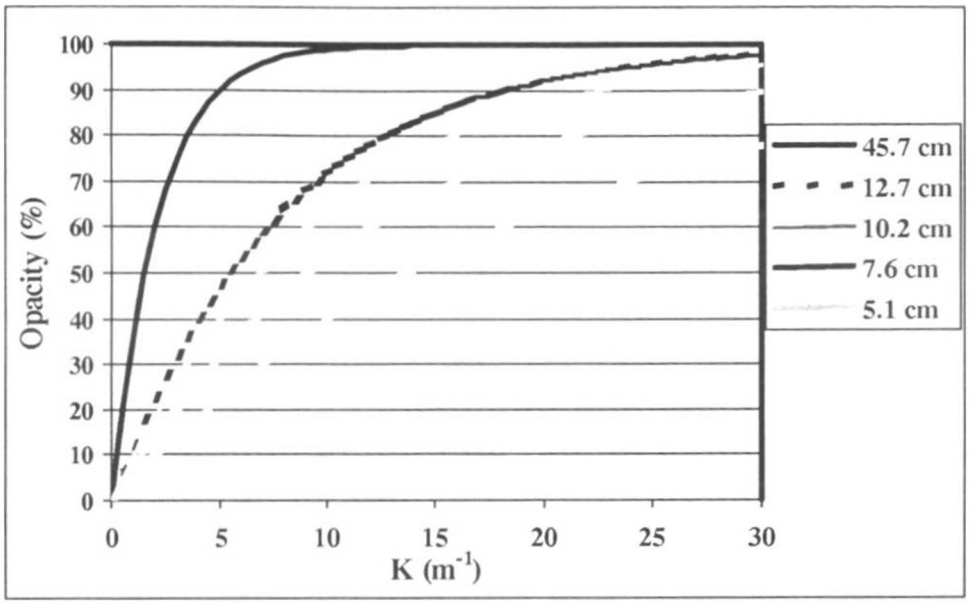


Figure 3.3: Smoke opacity vs. smoke density index K for different path lengths

3.5.3.2 Free-Acceleration Smoke Test Procedure

To be meaningful, diesel smoke measurements should be taken with the engine under load. Smoke levels under light-load conditions and at idle are normally very low, so that it is not possible to distinguish between clean vehicles and most smoky vehicles under these conditions. Only a small minority of seriously malfunctioning diesels exhibit measurable smoke opacity under idle or light-load conditions. Testing under these conditions, therefore, will identify only a minority of those vehicles with high smoke and PM emissions.

One commonly used technique for loading the engine to achieve a meaningful smoke measurement is the so-called "snap acceleration" or "free-acceleration" test. This test loads the engine with its own inertia, as the engine is rapidly accelerated from idle to full (governor-limited) speed. Although simple, convenient, and widely used, this test does not always give a reliable measure of smoke emissions in actual use, since the operating condition involved (rapid acceleration under no load) is not characteristic of normal engine operation. A combination of free-acceleration and steady-state smoke opacities, measured with the vehicle under load on a dynamometer, has been found to be a much better predictor of high PM emissions[26]. Free-acceleration test results are also very sensitive to proper conduct of the test. The test is fast and convenient, however, and is therefore widely used for on-road enforcement.

In order to reduce the variability and improve the accuracy of the snap acceleration procedure, a committee organized by the Society of Automotive Engineers (SAE) developed a standardized Recommended Practice for this test. This recommended practice has been designated J1667.

The core of the SAE J1667 procedure is a "snap-idle" sequence that is administered by the inspector, and which must be accompanied by opacity measurement. The sequence is as follows:

"Prior to each snap-idle cycle, the vehicle's engine shall be at normal low idle. From this position, the operator shall as rapidly as possible move the throttle to the wide open position. The operator shall hold the throttle at a wide open position until the engine has reached its maximum governed speed and an additional one to four seconds has elapsed. After this period, the throttle shall be fully released, and the engine allowed to return to normal idle. The engine shall be allowed to remain at idle for at least 5 seconds prior to the next snap cycle in the test sequence. This allows the engine's turbocharger (if equipped) to decelerate to its normal speed at engine idle, and helps to maintain repeat-ability between snap-idle cycles".

The result of the SAE J1667 test procedure is the average of three successive snap accelerations. For the test to be valid, the difference between the highest and the lowest value must be no more than 5% opacity - otherwise additional snap accelerations are performed until a sequence of three meets the criterion.

Although not specified in the J1667 procedure, EF&EE strongly recommends that a check of engine speed governor operation be performed before beginning the snap-idle smoke measuring procedure. This recommendation is based on experience in Thailand (where one truck engine was destroyed by overspeeding before this precaution was implemented) and in Sri Lanka (where the implementation of this check during our pilot roadside smoke inspection program identified several vehicles with malfunctioning speed governors). A malfunctioning governor was also found in one the 24 vehicles tested in our smoke survey in Arequipa, Peru. Had these problems not been detected by the preliminary governor check, those engines would likely have been damaged in the course of the J1667 test procedure.

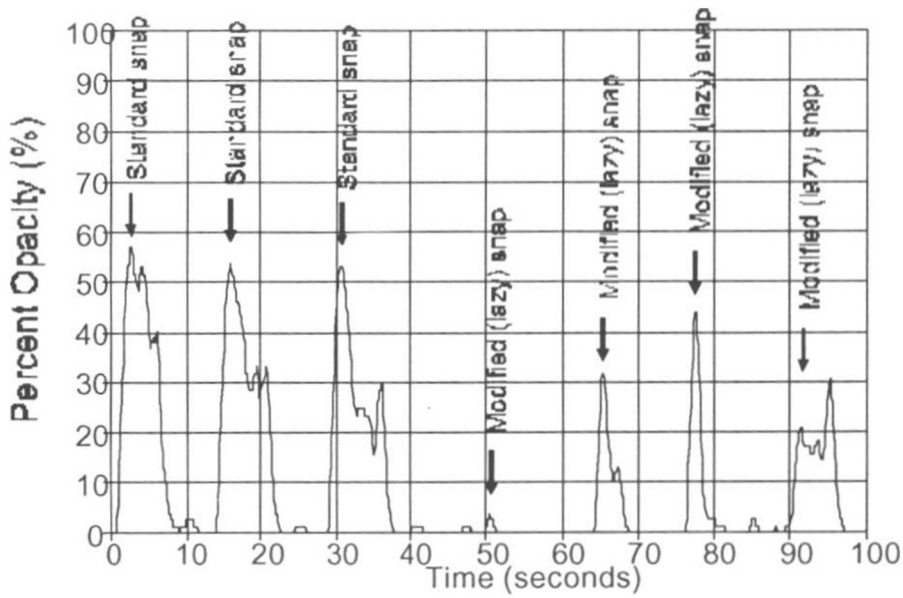
The governor check is performed with the engine in neutral or the clutch depressed, by slowly depressing the accelerator until the engine reaches its governed speed. If the engine governor fails to limit engine speed, the governor should be checked and repaired before the vehicle is tested. Otherwise, the governor may fail to limit the engine speed properly, and the engine is likely to be damaged in the free acceleration and maximum idle tests. An inoperative or improperly adjusted governor is a significant safety hazard, as well as making it unsafe to perform emissions tests. Vehicles exhibiting this problem should be required to undergo repairs and be presented again for emissions testing. Vehicles exhibiting an audible misfire in one or more cylinders, exhaust leaks that could compromise the test results, or such grossly excessive smoke emissions that they might contaminate the testing equipment should also be required to undergo repairs and be presented again for emissions testing.

Excessive engine speed during the governor test can be determined from the vehicle tachometer (if the vehicle is so equipped), by the use of an external tachometer, or by ear. The most likely indicator of overspeed would be valve float, which can be heard, but requires some training and practice to recognize. Use of an external tachometer generally requires access to the engine, which could delay the testing. Therefore, we recommend the use of the external tachometer only for fixed inspection stations, and not for roadside testing.

SAE J1667 differs from earlier versions of the snap-acceleration test procedure mostly in its calculation of the final result. Earlier snap-acceleration procedures recorded the peak smoke opacity reached during the acceleration. Many engines exhibit relatively narrow "needle" peaks,

which means that the maximum value registered may be affected by the response time of the instrument. A faster instrument will tend to see a higher peak in these circumstances. To allow for this, the SAE J1667 procedure includes a digital filtration procedure. The filtered value is calculated by the meter itself, internally, and then output. This filtering process tends to reduce the impact of "needle" peaks which contribute little to total PM emissions, while still providing a good measure of maximum smoke density under transient acceleration conditions.

The J1667 procedure is sensitive to operator style. It is important that the procedure conform exactly to the written directions every time, in order to obtain the most accurate results. Figure 3.4 illustrates what happens when the operator does not apply the accelerator correctly and consistently. This experiment was conducted by EF&EE staff during a field program in Costa Rica. The vehicle was one that exhibited moderately heavy smoke, but otherwise functioned properly. The first three accelerations were applied according to the procedure in italics above. The remaining three accelerations were applied "lazily", essentially violating to various degrees the requirement that the accelerator be depressed *"as rapidly as possible"*. Note that the smoke levels changed drastically from the first accelerations, and also became much more variable. The variation among the first three accelerations is quite small, a good indication that the procedure is being conducted properly. Strict adherence to the accepted procedure can easily make the difference between passing and failing the test. It is therefore recommended that the accelerator operation not be left to the vehicle driver, but that it be controlled by the person administering the test.



Opacity corrected to 76.2 mm path length

Figure 3.4: Effect of snap acceleration differences on smoke test results

3.5.3.3 Dynamometer Smoke Testing Procedures

Because of the weaknesses of the free-acceleration test procedure, an increasing number of diesel I/M programs are incorporating smoke opacity tests with the vehicle engine loaded by means of a chassis dynamometer. This allows smoke opacity measurements to be made under steady-state conditions, and allow the engine to be safely and repeatably loaded to defined test conditions. Commonly-used test conditions include "road load", with the dynamometer simulating the engine loading experienced in straight and level driving at moderate speed; and "lug down", which the dynamometer is used to load the engine to near its maximum torque. The dynamometer can also be used to simulate the effect of accelerating a loaded vehicle from stop - a more realistic indicator of transient smoke on acceleration than the free-acceleration test.

Different types of engine problems and tampering result in high smoke and PM under differing conditions. For example a dirty air filter or tampering with the maximum fuel stop tend to produce thick black smoke under full-load conditions, and are readily detected by a lug-down test. On the other hand, worn or damaged fuel injectors will increase smoke and PM emissions across the whole operating range, but may not result in thick black smoke at full power - especially if the vehicle owner turns down the maximum fuel setting in order to pass the test. For this condition, a partial-load test provides a better indicator. Tampering with the acceleration smoke limiter on a turbocharged engine can produce very high transient smoke levels during acceleration, but does not affect steady-state smoke. Thus, an acceleration test procedure can best detect this problem.

To effectively detect and identify the conditions that lead to high diesel PM emissions in use, we recommend that the dynamometer test procedure include both full-load and part-load measurements in steady state, as well as the SAE J1667 snap acceleration test procedure. It is important that the dynamometer test procedure be simple to carry out, so that excessive time is not lost in looking up dynamometer settings, etc. One convenient, fast, and effective procedure was developed during the pilot I/M testing on light-duty diesel vehicles.

In the approach used in the pilot I/M test program described in section 3.7, the chassis dynamometer is set to maintain a fixed speed, such as 60 km per hour. The vehicle is mounted on the chassis dynamometer, and the smoke opacity meter is installed in the exhaust. Suitable ventilation arrangements must also be provided to vent the exhaust smoke, which often can be very heavy.

The vehicle operator (who is an employee of the test facility, not the vehicle owner) accelerates to the defined speed on the chassis dynamometer, selects an appropriate gear (if the vehicle has a manual transmission), and then presses the accelerator to the floor. The dynamometer control system will increase the load as needed to prevent the speed from increasing beyond the setpoint. This results in the maximum engine power being delivered to the wheels. After allowing ten seconds for stabilization, the full-load smoke opacity is measured. The operator should also note the road power output as indicated on the dynamometer control screen. To guard against cheating by turning down the maximum fuel setting on the injection pump, a list should be kept of the normal power levels for each type of vehicle.

Part-load smoke opacity is measured at one-half the road power output produced at full load. To reach this condition, the vehicle operator gradually allows the accelerator pedal to rise until the power output displayed on the dynamometer control screen is one-half the full-load power output. Ten seconds are allowed for stabilization, after which the half-load smoke opacity is measured. The vehicle is then allowed to return to the idle condition. Three repetitions of the SAE J1667 snap acceleration are then performed before the vehicle is removed from the dynamometer. (NB. During the pilot testing, the snap accelerations were performed before or after the steady-state tests on the chassis dynamometer, according to convenience. For the periodic I/M program, however, it is recommended to standardize this).

The test procedure outlined above can readily be automated, and it is recommended that this be done in the full-scale I/M program. With this arrangement, a computer would control the dynamometer settings, display instructions to the operator, and record the measured smoke opacity, thus reducing the possibilities for corruption or tampering.

3.5.4 I/M Test Procedures for Motorcycles and Three-Wheelers

NOx emissions from motorcycles and three-wheelers tend to be low, so we recommend that I/M programs for these vehicles address HC, CO, and PM emissions. Since present evidence suggests that PM emissions – in the form of lubricating oil smoke – constitute the principal menace to public health from motorcycle and three-wheeler emissions, we recommend focusing especially on these.

The density or opacity of white or gray smoke from lubricating oil in the exhaust can be measured using the same types of light-transmission opacity meter used for black smoke measurements on diesels. However, the typically small size and sometimes-irregular shapes of motorcycle exhaust pipes make some adaptation necessary. In previous work in Bangkok[27], EF&EE staff developed an adaptation of the Wager full-flow smoke meter to measure white smoke from motorcycles. A similar adaptation was made to the Wager smoke meter to carry out the smoke opacity measurements for the pilot I/M program in this study. That adaptation is described in Section 3.6.2.

In EF&EE's work in Bangkok, we measured white smoke under two conditions: idle and free-acceleration. A follow-up study included measurement of mass particulate emissions from a sample of motorcycles selected to have a representative range of smoke opacity levels in the free-acceleration test. These tests showed only a modest correlation between free-acceleration smoke opacity and mass PM emissions, with correlation coefficients of 0.25 to 0.65, depending on the driving cycle.

Similar tests were done at ARAI, in Pune, on a limited sample of Bangladeshi three-wheelers[28]. Results of these tests (Figure 3.5) showed that high smoke opacity at idle is a good predictor of high mass PM emissions over the Indian driving cycle. Free-acceleration smoke opacity was not as good a predictor of PM emissions as idle opacity. Further, our experience in Bangkok showed great test-to-test variation in free-acceleration smoke opacity measurements for two-stroke vehicles. Thus, we recommend the use of the idle test rather than the free-acceleration test for smoke opacity in two-stroke vehicles. In our judgment, smoke opacity measurements under intermediate-speed conditions are likely to be even better predictors of in-

use PM emissions than idle smoke opacity, since these conditions are even more representative of normal operation. Data to support or refute this view are not available at present, but we recommend that this relationship be investigated in future studies.

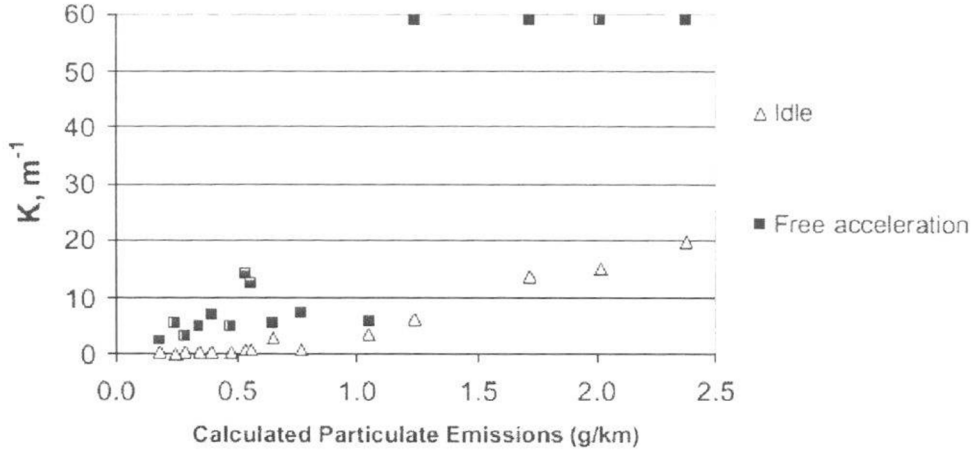


Figure 3.5: Smoke density vs. PM emissions for 3-wheelers tested with different oils, fuels, and maintenance conditions (reference 29)

Limited data on the effects of conventional idle I/M testing on mass pollutant emissions suggest that HC and CO concentrations at idle are modestly correlated with HC and CO emissions over the driving cycle. In an Indian study by Das and co-workers[29], motorcycles showing high HC or CO concentrations underwent simple carburetor adjustments, and - if those failed to reduce emissions - air filter and ignition repairs. Carburetor adjustments alone reduced average idle CO concentrations in the failing vehicle population by 50%, and HC concentrations by 41%. However, the average reductions in mass emissions over the Indian driving cycle were only 40% and 22%, respectively.

Abundant data from the U.S. demonstrate that – for four-stroke petrol vehicles – I/M emission tests using chassis dynamometers are more accurate than tests under idle and "two-speed idle" conditions. (The "two-speed idle" comprises testing under idle and 2500 RPM / no load) conditions. In our judgment, the same is likely to be the case for two-stroke vehicles – i.e. pollutant concentration and smoke opacity measured with the vehicle under load on a chassis dynamometer are likely to yield better predictors of mass emissions in real driving. Although data to support this judgment are not presently available, we recommend that a test program to assess the use of chassis-dynamometer based test procedures for two-stroke vehicles be conducted in the future.

3.5.5 Establishing In-Use Emission Standards

When implementing an I/M program, it is important that the emission standards established be neither too lax nor too stringent. If the standards are too lax, then the program will have little effect, since very few vehicles will fail. On the other hand, if the standards are too stringent,

then a very fraction of vehicles will fail. The resulting demand is likely to overwhelm the ability of existing repair facilities and parts supplies. Especially where public transport and commercial vehicles are concerned, high failure rates and inadequate repair facilities can be expected to create a political backlash against the program by owners of the affected vehicles, and may well lead to the program being suspended or cancelled due to political pressures. Even if the program is not cancelled, too-stringent standards create strong incentives for corruption and evasion.

The acceptable failure rate in a given I/M program is a matter of political judgment, and is affected by considerations of the relative difficulty and cost of correcting excessive emissions, as well as air quality conditions and the degree of public support for air quality improvements. In many cases, failure rates in the range of 10 to 30% have proven acceptable. The apparent severity of the PM2.5 problem along major roads in Colombo, the high percentage of vehicles with grossly excessive emissions, and the relative ease of correcting many of these through fairly minor repairs suggest that a relatively high percentage of initial failures could be tolerated in this case.

Assuming that the I/M program is effective, the distribution of emission levels can be expected to shift toward lower emissions as the worst polluters are identified and corrected. Thus, in future years, it should be possible gradually to tighten the emission standards while maintaining the same or lower failure rate. In this way, it should be possible gradually to reduce the maximum limits to levels representative of the technological capabilities of the vehicle population.

New or newly-imported vehicles can and should be held to more stringent standards than those currently in the vehicle population. Existing and proposed regulations require newly-imported (used or new) vehicles to comply with specified emission standards. Used vehicles, and a representative sampling of each new vehicle model, should be tested for such compliance before being allowed to register in Sri Lanka.

3.6. PREPARATION FOR THE PILOT I/M PROGRAM

3.6.1 I/M Program Plan

In February 2002, EF&EE submitted a preliminary plan for the pilot vehicle inspection and maintenance (I/M) program to be carried out as Task 2 of the project[30]. In it, EF&EE recommended that the pilot vehicle inspection and maintenance program be carried out in two phases. The first phase was intended solely to determine the statistical distribution of in-use emission levels in order to establish feasible emission standards or "cutpoints" for the I/M program. The second phase would then comprise further emission testing, with vehicles that exceeded the emission standards being required to undergo repairs and be retested.

During Phase 1 of the pilot vehicle I/M program, EF&EE proposed to measure the smoke opacities for sample populations of approximately 70 diesel heavy-duty trucks, 70 diesel heavy-duty buses, and 70 light-duty diesel vehicles (dual-purpose vehicles and motor cars). In addition, it was proposed to measure smoke opacity together with exhaust HC and CO concentrations on sample populations of approximately 70 two-stroke three-wheelers and 70 two-stroke motorcycles.

During Phase 2, the emission standards established during Phase 1 were to be applied to further samples of these same types of vehicles. Motorcycles and three-wheelers having emissions that exceeded the established standards would receive on-site adjustments and then be retested. Vehicles that still failed after this service would be required to undergo further repairs off-site, and then be presented for a follow-up test. Diesel vehicles with smoke exceeding the established standard would also be required to undergo repairs off-site, and then be presented for a follow-up test (it was not considered feasible to carry out diesel vehicle adjustments on-site). Emission reductions and repair costs would be tabulated, and used to fine-tune the recommendations for a full-scale vehicle I/M program.

3.6.2 Analyzer Specifications and Procurement

The Inception Report discussed in detail the instruments required to implement the pilot vehicle I/M program. These instruments included smokemeters to measure black smoke from diesel vehicles and white smoke from two-stroke vehicles, and portable gaseous emission analyzers designed to measure high HC concentrations (i.e. 15,000 ppm) and CO emissions from two-stroke vehicles.

AirMAC issued calls for bids for two smokemeters and two gaseous emission analyzers, and eventually procured two Wager 6500 smokemeters, and two Horiba MEXA 554J gas analyzers. The Wager 6500 is available with both full-flow and partial flow sensing heads. While the bid specifications called for the meters to be of the partial flow design, the smokemeters actually supplied to the program were equipped with the full-flow heads. These

full-flow sensing heads are not suitable for use with small-diameter exhaust pipes such as those found on three-wheelers, motorcycles, and many light-duty diesel vehicles. The small-diameter smoke plumes produced by these exhaust pipes are difficult to measure accurately, resulting in unacceptable levels of error in the determination of smoke density (K) values.

Because of delays in receiving the AirMac smokemeters, the Phase 1 diesel testing was carried out with a Wager 6500 smokemeter belonging to EF&EE. This meter was equipped with the partial-flow sensing head. The problem with the full-flow sensing heads was not identified until the EF&EE project team unpacked the AirMac smokemeters in preparation for the Phase 2 testing. The EF&EE meter had by this time been returned to California, and it was impractical either to return that meter or to secure partial-flow heads for the AirMac meters in the time available.

To be able to apply the full-flow smokemeters to small exhaust pipes, the smoke testing team designed an adapter for the full-flow meters in the form of a truncated cone. The narrow end of the cone fit into the end of the exhaust pipe, adapting it to a larger pipe 60 mm in diameter. This larger pipe was provided with small holes for the smokemeters's light beam. The inlet diameter for one of the sampling cones was approximately 2 cm, so that it could be used for motorcycles and three-wheelers; while the other was approximately 4 cm in diameter, making it suitable for light-duty and medium-duty diesel vehicles.

3.6.3 Standard Operating Procedures

To help ensure the accuracy and reproducibility of the test results, EF&EE developed standard operating procedures (SOPs) for checking and calibrating the Wager 6500 smokemeters and Horiba MEXA 554J gas analyzers and for carrying out the emission meausurements. Copies of these SOPs are given in Appendix B:

- SOP 001: Measuring Gaseous Emissions Using Horiba MEXA 554J 4-Gas Analyzer
- SOP 002: Measuring Smoke Emissions Using Wager Smoke Meter

In addition to information such as the purpose, overview, safety precautions, and quality control provisions, these SOPs provides step-by-step procedures to inspect, prepare and operate or calibrate the Wager and Horiba instruments.

3.6.4 Training of Trainers

In the course of Phases 1 and 2 of the pilot I/M program, EF&EE staff trained a number of technical school instructors and motor vehicle examiners to carry out the vehicle emission measurements. These persons then worked with EF&EE staff to perform the emission measurements at roadside, thus gaining additional experience and familiarity. In addition, as part of the plans for Phase 2 of the pilot I/M project, EF&EE prepared and presented two workshops on vehicle emissions diagnosis and repairs. These workshops were designed primarily to familiarize vehicle service managers with the plans for Phase 2, to inform them of the principal causes of high emissions from diesel and two-stroke vehicles, and to provide guidance for diagnosing and repairing vehicles that failed emission test. The workshop on causes and diagnosis of high diesel smoke was held at the Automotive Engineering Technical Institute on November

27, and the workshop on inspection and repair of two-stroke vehicles was held December 4 in the same location.

A separate training workshop on vehicle emissions inspection for motor vehicle examiners and traffic policemen was held November 30th. Attendees at this workshop included motor vehicle examiners and traffic police commanders from all over Sri Lanka. The presentation focusesd on the design of the I/M program and emission measurement techniques, including a hands-on demonstrations of diesel smoke opacity and gaseous pollutant concentrations in gasoline vehicle exhaust.

3.7. PHASE I EMISSION TESTING AND RESULTS

The pilot I/M program plan called for diesel smoke opacity measurements on representative sample populations of approximately 70 heavy-duty trucks, 70 heavy-duty buses, and 70 light-duty diesel vehicles (dual-purpose vehicles and motor cars). In addition, measurements of smoke opacity, CO and HC concentrations were to be performed on representative sample populations of approximately 70 two-stroke three-wheelers and 70 two-stroke motorcycles.

This chapter presents the Phase 1 emission data for heavy-duty diesel trucks and buses, light-duty diesel vehicles, two-stroke three-wheelers and motorcycles, and light-duty petrol vehicles.

3.7.1 Heavy-Duty Diesel Lorries and Buses

Emission measurements on heavy-duty diesel lorries (trucks, in American English) and buses were carried out during a mission to Sri Lanka between September 30 and October 8. Because the smoke opacity meters ordered by AirMac were not available at the time of the mission, these measurements were made using a similar Wager 6500 smokemeter belonging to EF&EE. Although the smokemeter was sent to Sri Lanka under a carnet that should have allowed it to be imported temporarily without difficulty, several days of potential testing time were lost due to delays by Sri Lankan customs in clearing the equipment.

The EF&EE smokemeter was equipped with the Wager partial-flow sensing head. This head is designed to be partly inserted in the exhaust pipe, and to conduct part of the exhaust flow to a five-inch (127 mm) optical path between a light sending unit and a light receiving unit. The smoke testing team found the unit to be simple and straightforward to operate. Unlike full-flow smoketers, there is no need to mount the unit on the end of an exhaust pipe – instead, it is enough just to hold the unit with the "nose" inserted in the pipe. This greatly speeded the emission testing process. With practice and teamwork among the measurement crew and the traffic police, it proved possible to stop, test, and record the data from more than 15 diesel vehicles per hour.

A total of 71 heavy-duty diesel lorries and 69 heavy-duty diesel buses were stopped and tested for smoke opacity. Smoke tests on trucks were carried out mainly across from the Automotive Engineering Technical Institute near the Oduguwatta intersection in Colombo. Some tests were also carried out beside the Negombo airport road, and near the junction with the High-Level road. All of the tests were performed according to the snap acceleration test procedure specified in SAE Recommended Practice J1667. Based on previous experience by EF&EE, a preliminary check of the engine speed governor's function was added to this test, to avoid engine damage and injuries that could occur if the engine speed governor were not effective. This was found to be the case for several of the vehicles stopped, and these vehicles therefore were not tested.

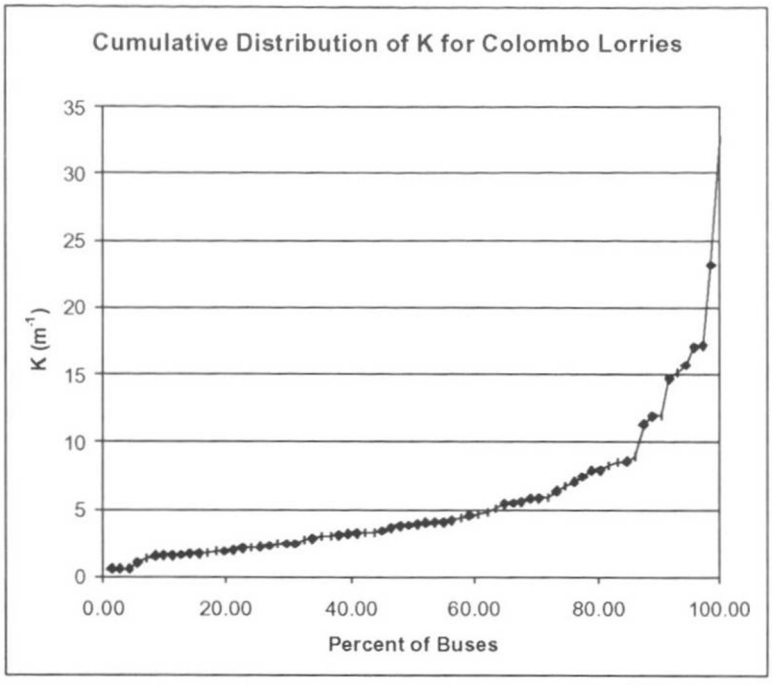


Figure 3.6: Cumulative distribution of the K value for lorries in Colombo.

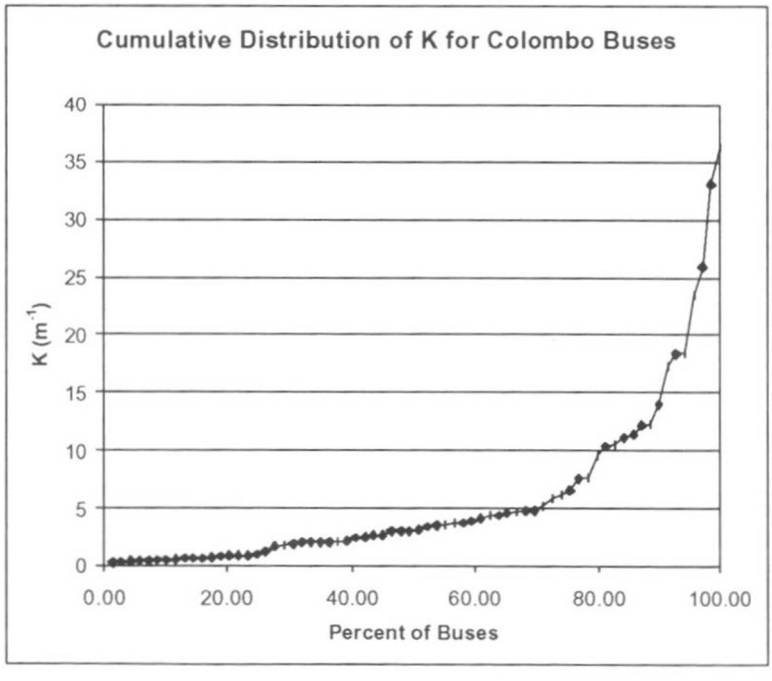


Figure 3.7: Cumulative distribution of the K value for buses in Colombo.

Of these 71 lorries, 12 were equipped with turbochargers; the rest had naturally aspirated engines. The cumulative distribution graph for the K value is shown in Figure 3.6. The mean smoke density (K) value was 5.7 m^{-1}, while the median value was 3.9 m^{-1}. Eighty two percent of the measured K values were less than 8.0, which was therefore suggested as an interim smoke opacity standard.

As for the heavy-duty buses, a total of 69 vehicles were tested in the Colombo area using the SAE J1667 snap acceleration procedure. Of these 69 vehicles, two were equipped with turbo-chargers, and the rest were naturally aspirated. The cumulative distribution graph of the K value for the bus measurements is shown in Figure 7. The mean K value was 5.9 m^{-1}, and the median was 3.0 m^{-1}. Seventy-eight percent of the buses had K values less than 8.0 m^{-1}, suggesting that this would be an appropriate interim smoke standard for these vehicles as well.

In our testing, a substantial difference in emissions performance was observed between the large city buses used for public transport and the smaller, privately operated air-conditioned buses. Nearly all of the public transport buses displayed low to very low smoke opacity, suggesting that these buses are reasonably well maintained. On the other hand, many of the smaller, privately operated air-conditioned buses exhibited high to very high levels of smoke. These vehicles are typically imported in used condition, and the condition of the engine and injection system is frequently poor.

3.7.2 Light-Duty Diesel Vehicles

The test plan called for smoke opacity to be measured from 70 light-duty diesel vehicles. These measurements were to be made in both the SAE J1667 snap acceleration test procedure and in steady-state operating conditions on a chassis dynamometer. The Mechanical Engineering Department of the Open University of Sri Lanka permitted us to use the light-duty chassis dynamometer in their automotive engineering laboratory for this purpose. Because of time limitations and ventilation problems, however, it was possible to test only 29 light-duty vehicles in this way.

The vehicles subjected to dynamometer testing were recruited by the Traffic Police from roads immediately adjacent to the Open University campus. Drivers were requested, but not ordered, to bring their vehicles to the automotive engineering laboratory for testing. Once there, the vehicle was subjected to a snap acceleration test, then mounted on the dynamometer. Smoke opacity was measured with the vehicle operating at 60 km/hour and full engine load, and then again at half load. Full load was achieved by setting the dynamometer to maintain 60 km/hour, and then pressing the accelerator to the floor. The dynamometer power absorbed in this condition was noted, and the smoke opacity was measured. The accelerator pedal was then allowed to rise until the dynamometer power absorption reached half of the former level, and the opacity was measured again.

Each test took about 15 minutes, so that the number of vehicles that could be tested was limited. Most of this time was spent in maneuvering the vehicle onto and off of the dynamometer, as the dynamometer installation had not been designed for high-volume testing. Had the system been designed for high throughput, the test itself could have been carried out in two or three minutes.

Because vehicle drivers were given the option to participate in the dynamometer testing or not, there was concern whether the sample of vehicles that chose to participate would be representative of the larger population. To resolve this question, another sample of 40 vehicles were subjected to snap acceleration smoke opacity checks at roadside.

The cumulative distribution graph for the measured K values from light-duty vehicles is shown in Figure 3.8. As this figure shows, the distribution of snap acceleration smoke opacity values for the roadside sample does not differ significantly from that of the vehicles subjected to dynamometer testing, indicating that the latter sample is probably representative.

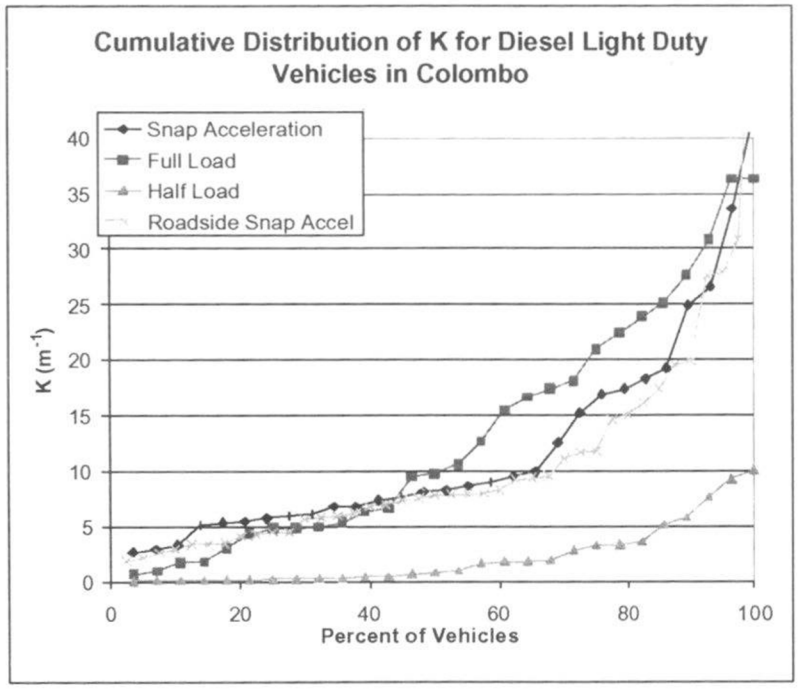


Figure 3.8: Cumulative distribution of K values for light-duty diesel vehicles in Colombo.

Figure 3.9 plots the K values measured in the snap acceleration and half-load test procedures against the result of the full-load test for the same vehicle. As this figure shows, the correlation between the snap acceleration and full-load smoke density values is poor. Some vehicles exhibited high smoke in snap acceleration, but not at full load. Others exhibited the reverse pattern. Thus, it is apparent that – for light-duty vehicles at least – the snap acceleration test procedures is not an adequate substitute for full-load, steady-state testing.

As expected, the smoke opacity values observed at half load were much lower than in snap acceleration or full-load conditions. However, a substantial number of light-duty vehicles still displayed elevated smoke density under half-load conditions. High smoke density at full load may indicate either engine overfueling (relative to the available air supply) or an engine mechanical problem that results in poor mixing between air and fuel. Only this last type of problem is likely to result in high part-load smoke opacity as well. This type of engine

problem is of great concern from the standpoint of air quality, since it tends to result in "gross emitters", with high PM emissions over the entire driving cycle, and not just in fraction of the driving time that the engine is operating at or near full load.

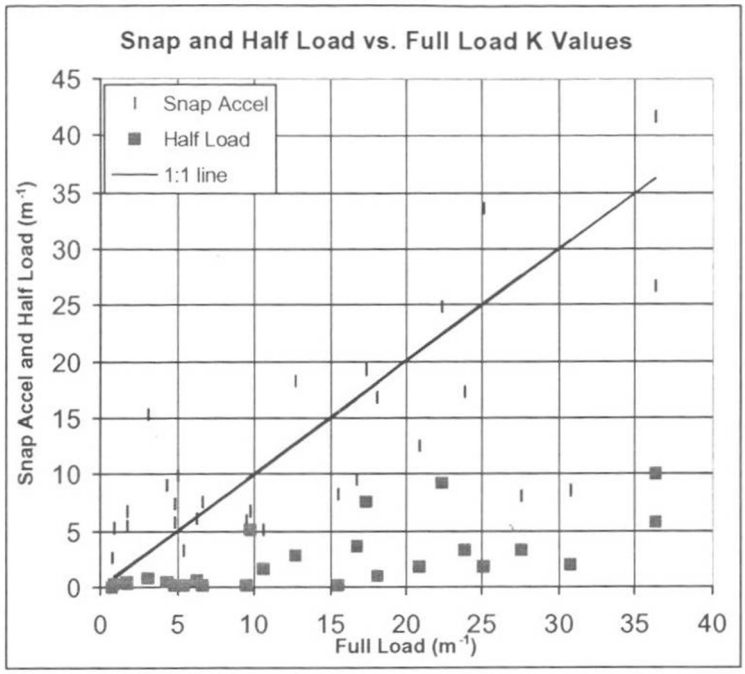


Figure 3.9: Smoke densities in full load vs. snap acceleration

3.7.3 Two-Stroke Three Wheelers and Motorcycles

The pilot I/M plan called for measurements of smoke opacity together with exhaust HC and CO concentrations to be performed on sample populations of approximately 70 three-wheelers and 70 motorcycles. These measurements could not be carried out during the mission of September 30 to October 8, as the gas analyzers ordered by AirMac had not yet been released from Sri Lankan customs. Therefore, these measurements were carried out during the subsequent mission, which had been intended for Phase II testing only.

A total of 79 two-stroke vehicles were tested for white smoke opacity and gaseous emissions in the Colombo area. The white smoke and gaseous emissions were measured at idle and at approximately 3,500 rpm with no load. Although the plan had been to check the 3500 RPM condition with a tachometer, the tachometers available proved unable to measure engine RPM accurately on these vehicles. Therefore, after a period of experimentation, it was decided to approximate the 3500 RPM condition by ear. Since the smoke and gaseous pollutant concentrations were not sensitive to small differences in engine speed, this approximation is not considered to have had a significant effect on the results. It is recommended that suitable induction tachometers be identified and employed for future I/M testing, however.

Out of the 79 vehicles tested, 63 were three-wheelers and 16 were motorcycles. The limited number of motorcycles tested in Phase I was due to the shortage of time available for this testing, as the delay in receiving the smokemeters from Sri Lankan customs left only a single day available for Phase I testing on two-stroke vehicles. Another contributing factor was the unexpectedly low fraction of two-stroke motorcycles in the on-road motorcycle population at the test site, which meant that few motorcycles were available to test during that period.

For the smoke density measurements on the two-stroke vehicles, the AirMac smokemeters were fitted with conical adapters, as discussed in section 3.6.2. The resulting path length for the smoke measurements was 61 mm. The mean K values at idle and 3,500 rpm were 1.1 and 1.2 m^{-1} for three-wheelers, and 2.5 and 3.9 m^{-1} for motorcycles, respectively. Cumulative distribution plots of the measured K values are given in Figure 10.

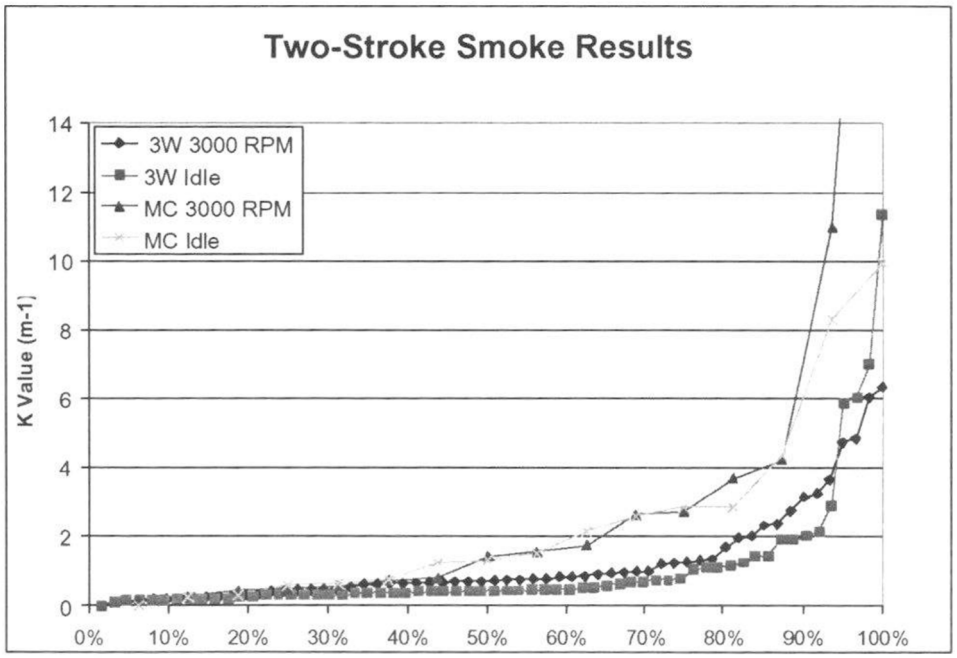


Figure 3.10: Cumulative distribution of white smoke K values for three-wheelers and motorcycles in Colombo.

At first, our analysis of exhaust HC and CO concentrations among three-wheelers and motorcycles was based on the as-measured results. These results were used to develop the interim emissions standards applied in Phase 2. After analyzing the two-stroke data in greater depth, however, we found that many of the exhaust samples - especially for the three-wheelers - exhibited a very high degree of dilution by atmospheric air. The dilution problem appears to be inherent in the design of the exhaust system for these vehicles. It is not possible to insert the probe deeply enough into the exhaust to get beyond the point where air is sucked into the exhaust pipe by the exhaust pulsations. Since the degree of dilution varied from vehicle to vehicle, we concluded that the recommended emission standards should be based on emission concentrations corrected for dilution. Because the four-gas concentration measurements included oxygen and CO_2 in addition to HC and CO, it was possible to calculate the percentage

dilution from the measured exhaust concentrations.

The cumulative distribution graphs for the HC concentrations before and after correction for exhaust dilution are shown in Figure 3.11 and Figure 3.12, respectively. Cumulative distribution graphs for the CO concentration before and after the correction are shown in Figure 3.13 and Figure 3.14, respectively.

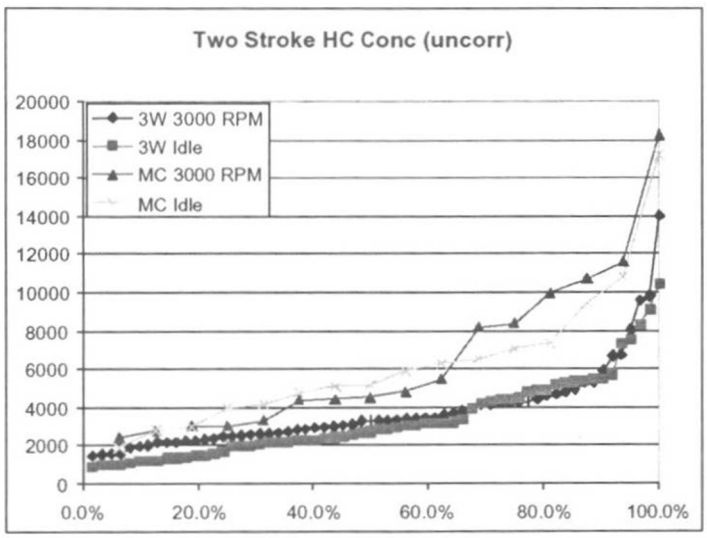


Figure 3.11: Cumulative distribution of HC concentration for three-wheelers and motorcycles in Colombo – not corrected for sample dilution

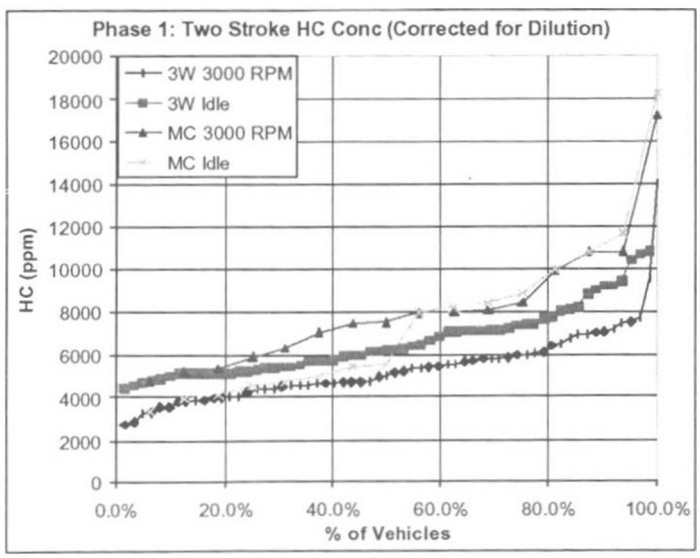


Figure 3.12: Cumulative distribution of HC concentration for three-wheelers and motorcycles in Colombo – corrected for sample dilution

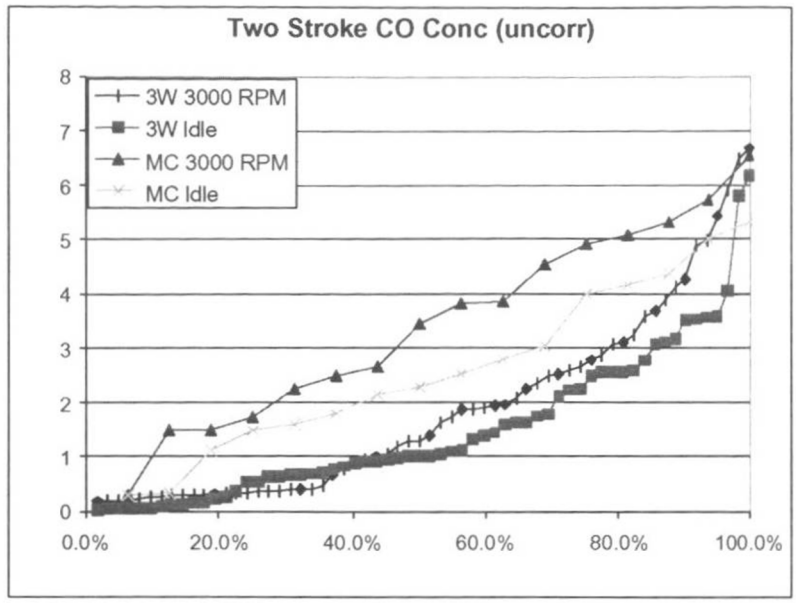


Figure 3.13: Cumulative distribution of CO concentration for three-wheelers and motorcycles in Colombo – not corrected for sample dilution

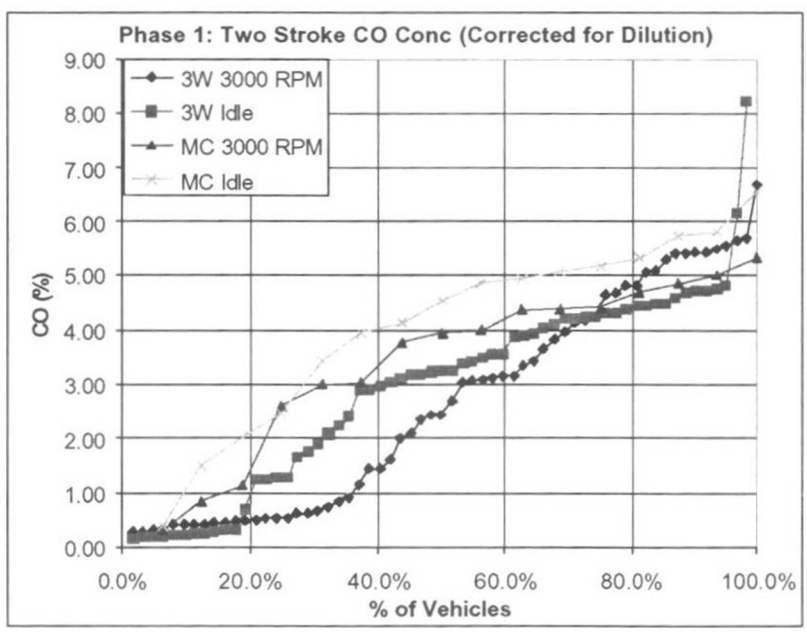


Figure 3.14: Cumulative distribution of CO concentration for three-wheelers and motorcycles in Colombo – corrected for sample dilution

3.7.4 Light-Duty Petrol Vehicles

Emission testing on four-stroke petrol vehicles had not been planned as part of this project, as these vehicles were outside the original scope. However, the delay experienced in releasing the AirMac smokemeters from Sri Lankan customs left the project team with time available to carry out these tests. A total of 36 petrol passenger cars were tested for gaseous emissions in front of the RMV offices. The test conditions were idle and 2500 RPM with no load. Analysis of these data showed that – unlike the motorcycles and three-wheelers – only a few vehicles displayed significant exhaust dilution. Nonetheless, for consistency, the results of these measurements were corrected for dilution as well. The resulting cumulative distribution graphs for the HC and CO emissions are shown in Figure 3.15 and Figure 3.16, respectively.

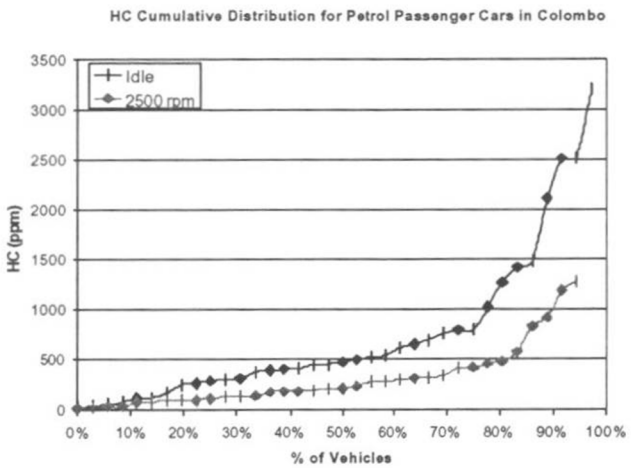


Figure 3.15: Cumulative distribution of HC concentration for petrol cars in Colombo

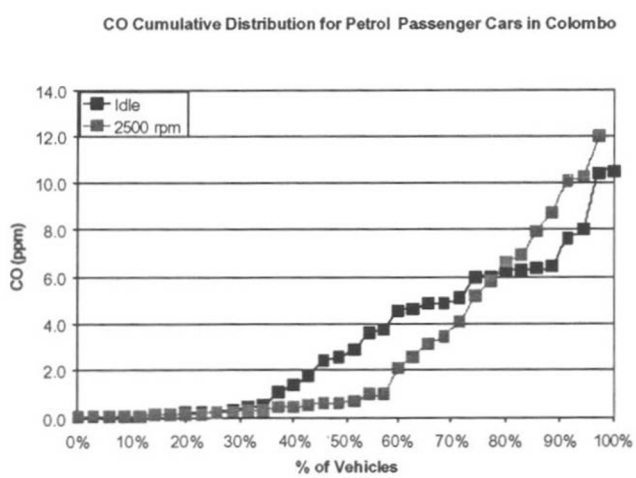


Figure 16: Cumulative distribution of CO concentration for petrol cars in Colombo

3.8. RECOMMENDED EMISSION STANDARDS

This chapter presents the interim emission standards (cut points) selected for the diesel and two-stroke vehicles. These interim emission standards were selected and recommended on the basis of the statistical distributions of emission levels developed in the Phase 1 testing and presented in Section 3.7. The recommended emission standards were chosen to achieve reasonable and feasible failure rates in the initial I/M inspections. After approval by AirMac and the Vehicle Emission Control Committee, these standards were then applied in Phase 2 of the pilot vehicle I/M program. These data also serve as the basis for recommending initial emission standards for the proposed full-scale I/M program.

3.8.1 Recommended Emission Standards for Diesel Vehicles

The diesel smoke opacity data collected during Phase 1 are summarized in Figure 3.17. Based on these results, EF&EE recommended interim smoke opacity standards of 8.0 m^{-1} in the SAE J1667 snap acceleration test procedure, rather than the more stringent standard of 3.22 m^{-1} stated in the existing regulation. Based on the data collected in Phase 1, EF&EE's recommended standard would be expected to result in roughly 20% of buses, 20% of trucks, and 40% of light duty vehicles failing and having to undergo repairs. Enforcement of the 3.22 m^{-1} standard, if it were possible to do so, would cause 50% of buses, 60% of trucks, and 90% of light-duty vehicles to fail. In EF&EE's judgment and experience, that would be likely to lead to political unrest, widespread evasion, and the failure of the I/M program.

The projected failure rate of 40% for light-duty diesel vehicles is relatively high - high enough to lead to political difficulties in many cases. To achieve a more-comfortable 20% failure rate, however, it would have been necessary to relax the proposed smoke limit to more than 17 m^{-1}. The air quality implications of allowing such high smoke emissions would have been unacceptable, in our view. Further, our judgment was that it would be better and more consistent to enforce the same smoke limit for light-duty and heavy-duty diesels. Finally, our experience and the results of the Phase 2 test program show that the proposed emission limit of 8 m^{-1} can be achieved readily and at modest cost by nearly all light-duty diesel vehicles.

Because of logistical problems involved in chassis dynamometer testing on the Open University's laboratory system, it was decided not to include such testing in Phase 2 of the Pilot I/M program. However, EF&EE still very strongly recommends that the future vehicle I/M program include full-load and half-load smoke opacity measurements on a chassis dynamometer as part of the periodic inspection. Recommended initial emission standards for these test modes are K values of 8 m^{-1} in full load and 5 m^{-1} at one-half load. While about 60% of the light-duty diesel vehicles tested would have failed the proposed full-load emission limit, most of these vehicles could readily be brought into compliance by very simple measures - changing the air filter and adjusting the maximum fuel stop on the fuel injection pump.

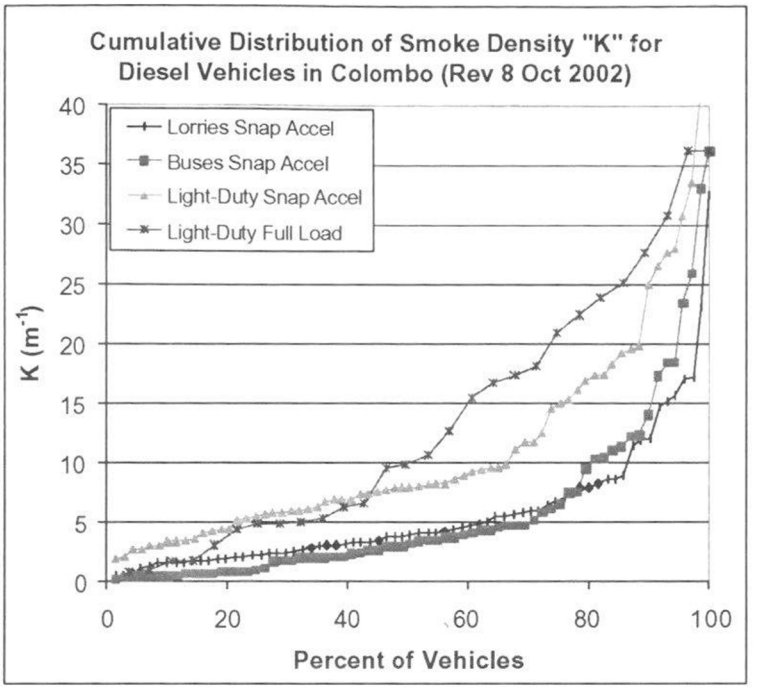


Figure 3.17: Distribution of smoke density coefficient "K" for diesel vehicles in Colombo

3.8.2 Recommended Emission Standards for Two-Stroke Petrol Vehicles

The smoke emission results for two-stroke three-wheelers and motorcycles were summarized in Figure 3.10, while Figure 3.12 and 3.14 show the distributions of corrected HC and CO concentrations, respectively. Based on these data, EF&EE recommended limiting the smoke density for two-stroke three-wheelers to 2.0 m^{-1}, while HC and CO concentrations would be limited to 7500 ppm and 5.0%, respectively, after correcting for dilution. These emission limits would apply both at idle and at 3,500 RPM. Based on the data collected, these limits were expected to result in failure rates of 23%, 23%, and 18%, respectively, with a total overall failure rate of 41%. The overall failure rate is less than the sum of the individual rates, since many vehicles would fail more than one emission standard. The relatively high failure rate was considered politically acceptable in this case, since three-wheelers are primarily commercial vehicles, and since it is driven substantially by smoke emissions, which can be reduced to passing levels by using the correct type and amount of lubricating oil. High HC and CO emissions (especially at idle) can usually also be corrected readily and at very low cost by simple carburetor adjustments.

For two-wheeler motorcycles, the proposed emission limits were less stringent - smoke density of 4.0 m^{-1}, and HC and CO concentrations of 12,000 ppm and 6%, respectively, after correction for exhaust dilution. From the limited data available, these standards were expected to result in failure rates of 29% for smoke, 10% for HC, and 14% for CO, with an overall failure rate of 40%. This relatively high failure rate is considered politically acceptable, since

it is driven primarily by smoke emissions, and these can readily be reduced by using the correct type and amount of lubricating oil.

3.8.3 Recommended Emission Standards for Four-Stroke Petrol Vehicles

Four-stroke petrol vehicles were not included in the Phase 2 pilot program, and it was therefore not necessary to develop interim emission standards for them. If such a program were to be undertaken in the future, however, we would recommend emission limits of 6.0 percent CO and 1000 ppm HC, at both idle and 2500 RPM. Based on the limited sample collected, the recommended CO limit would result in failure of about 36% of the vehicles, while the HC limit would fail 25%. The overall failure rate would be 44%, since some vehicles would fail both HC and CO. Taking account of the relative ease with which HC and CO emissions can be reduced by adjusting the air-fuel mixture on these (primarily carbureted) vehicles, this failure rate would likely be politically sustainable in our view. An even lower CO standard – of the order of 4% – could be justified on the basis of emissions and the fuel economy benefits, but the resulting failure rate of 53% might be too high to be sustainable politically.

In addition to HC and CO emissions, we recommend measuring the smoke opacity from four-stroke petrol vehicles as well. Data from studies in the U.S. show that a small minority of "white smokers" account for a large percentage of total PM emissions from petrol vehicles. These vehicles can readily be detected by smoke opacity measurements. The suggested smoke opacity standard of 2.0 m^{-1} would be the same as that suggested for two-stroke three-wheelers. While the failure rate for this standard would likely be less than 2%, the vehicles so identified would be sources of grossly excessive PM emissions, and thus well worth identifying for repair.

3.9. PHASE TWO EMISSION TESTING AND REPAIR RESULTS

During Phase 2, the plan for the pilot vehicle I/M program called for the interim emission standards established on the basis of the Phase 1 results to be applied to a further sample of each type of vehicles. Vehicles with emissions exceeding the interim standard levels were considered to be in violation of the existing motor vehicle act provision forbidding annoying or hazardous exhaust emissions, and were required to undergo repairs. Compliance with this requirement was to be enforced in the same way as other violations relating to vehicle equipment - by holding the vehicle registration documents until the problem was corrected.

The nature of the mandatory repairs was different for the two-stroke petrol vehicles than for the diesels. Common causes of high emissions from two-stroke motorcycles and three-wheelers can be remedied by adjusting the air-fuel ratio, replacing or regapping the spark plug, and (for excessive smoke) emptying the fuel tank and refilling it with a correct mixture of low-smoke 2-T oil and petrol. For vehicles with separate 2-T oil reservoirs, adjusting the oil feed rate and replacing the oil with an approved low-smoke 2-T oil will correct most smoke problems. These adjustments were performed on-site at the test location. Vehicles that still failed the test after this service were required to undergo further repairs off-site, and then be presented for a follow-up test.

The common causes of high smoke emissions from diesel vehicles cannot practically be corrected at roadside. Therefore, diesel vehicles with smoke exceeding the established standard were required to undergo repairs off-site, and then be presented for a follow-up test. The owners of vehicles that failed the test were given a list of qualified diesel repair shops that had agreed to participate in the pilot program. Mechanics from these qualified repair shops participated in training on diesel smoke diagnosis, and were instructed to record the repairs done to correct each smoke problem and the costs of those repairs.

From the results of the Phase 2 program, we expected to be able to project the following with some accuracy for each type of vehicles:

1) What percentage of failing vehicles of each type can successfully be brought into compliance with the standard;
2) The average cost of repairs and the statistical distribution of repair costs; and
3) What smoke and emissions levels are achievable through correct maintenance (and correct lubrication, in the case of two-stroke engines)

3.9.1 Diesel Vehicles

The Phase 2 emission testing on diesel vehicles was conducted on November 29 and December 2, 2002. Testing November 29 was across from the AETI office, Orugodawatta; and that December 2 was beside the High Level Road, Colombo 5. SAE J1667 smoke opacity measurements were performed on a total of 241 diesel vehicles: 81 buses, 87 lorries, and 73 light-duty vehicles (dual-purpose vehicles, light trucks, SUVs, Jeeps, and passenger cars). Several other vehicles were stopped, but could not be tested because of engine or exhaust system problems.

The cumulative distribution of smoke density values for the Phase 2 diesel vehicles is shown in Figure 3.18. Compared to distributions measured in Phase 1, the Phase 2 data show generally higher smoke levels. This is probably attributable to the difference in vehicle selection method between the two tests. In Phase 1, vehicles were selected randomly, to obtain a representative distribution. In Phase 2, the purpose was to identify and cite failing vehicles, so that vehicles exhibiting visibly high smoke emissions were more likely to be stopped and tested than less-smoky vehicles.

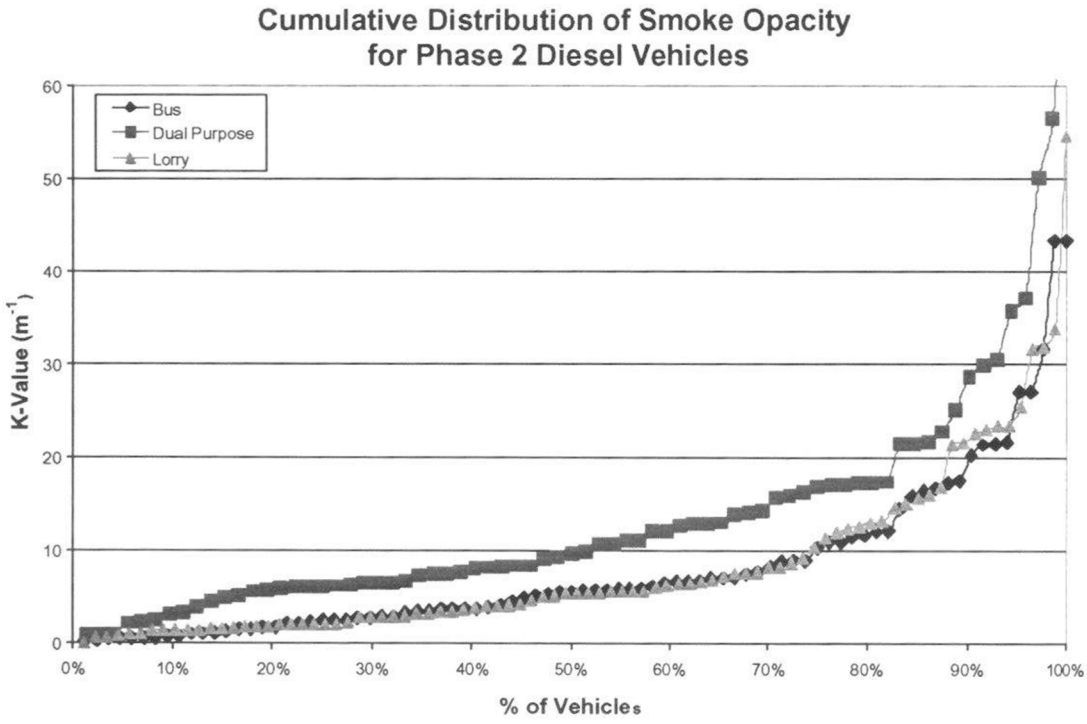


Figure 3.18: Cumulative distribution of smoke density for diesel vehicles tested in Phase 2.

Of the 241 vehicles tested, 91 failed the recommended smoke density standard of 8.0 m^{-1} and were required to undergo repairs. The failing vehicles comprised 23 buses (28% of the buses tested), 25 lorries (29% of the lorries tested), and 43 light-duty vehicles (59% of the light-duty vehicles tested). Except for two light-duty vehicles, all of the failing vehicles were given

probation citations on the spot. The drivers were instructed to have their vehicles diagnosed and repaired, and then to bring them to Registry of Motor Vehicles (RMV) office to be retested. They were also asked to record what repairs were made and the cost of the repairs. Several other vehicles were found to marginally exceed the smoke opacity limit, with K values between 8.1 and 8.4 m^{-1}. These were not cited, as it was considered that the degree of exceedance was within the limits of error of the test procedure.

EF&EE received after-repair emissions data from only 35 of the 91 diesel vehicles cited during Phase 2. It is not clear to us whether the remaining vehicles returned and were cleared by RMB and/or the traffic police, without the data reaching us; or whether the owners of these vehicles chose to ignore the citation, and were able to do so successfully. The vehicles for which after-repair data have been returned to EF&EE comprise 8 buses (35% of the buses cited), 9 lorries (36%), and 18 dual-purpose vehicles (43%). In addition, we received data for three vehicles that had not been cited for excessive smoke as part of this program. One of these had been cited for a broken exhaust pipe, and told to return for a smoke test after the exhaust pipe was repaired (it passed). The other two vehicles may have been cited for safety violations, or for excessive smoke outside of the Phase 2 program.

For 26 of the 35 vehicles, the after-repair data provided to us included the repair costs. The emission data before and after repair, as well as the cost and type of repair performed, are tabulated in Table 3.10. In 10 cases, unfortunately, the after-repair smoke data were not recorded - it was only recorded that the K value was less than 8. This is cause for concern, since it suggests that the smoke levels after repair may not actually have been measured for those vehicles.

For those vehicles for which after-repair smoke data were available, the reductions in smoke density ranged from 14 to 96%, with an average reduction of 67%. In only two cases did the smoke value after repair exceed 8.0 m^{-1}. The values in these two cases were 8.5 and 9 m^{-1}, or very close to the standard. The repair costs ranged from 1,220 to 84,190 Rs (or about USD 15 to 900), with an average of 11,950 Rs (about USD 130). As anticipated, most of the repair/service work involved the injection nozzles and the fuel injection pump.

Broken down by vehicle type, the average repair costs for buses were Rs. 8,123 (USD 87), and for trucks they were Rs. 12,824 (USD 138). The average for light-duty vehicles was Rs. 13,252 (USD 142), but this average was skewed by one vehicle that underwent a full engine overhaul. Excluding this vehicle, the average for light-duty vehicles would have been Rs. 7341 (USD 79).

The cost data received to date show relatively low costs compared to the emission reductions achieved. However, these averages must be treated with caution, since they represent less than one third of all the smoke citations issued. Further, one might expect that these data would be biased toward the low side. The higher the cost of the repairs needed, the longer it would be likely to take the vehicle owner have the repairs made, and the more likely the owner would be to ignore the citation in the hope that his or her noncompliance would be overlooked.

Table 3.10: Smoke density reductions and repair costs for diesel vehicles tested in Phase 2

Vehicle No.	Type of Repair	K Factor (m^{-1})		Cost of Repair (Rs)
		Before Repair	After Repair	
58-2827	A and B	9.1	< 8	3,500
63-1883	A and B	17.5	5	7,650
GD-1933	B and C	14.1	< 8	3,870
62-3812	E	11	< 8	3,500
60-3011	A and B	31.6	< 8	2,900
57-5996	A	21.7	< 8	5,800
41-4162	B and D	22.5	3	3,257
59-5051	A and D	15.6	1.2	3,100
60-4748	A; B and F	13.9	2	7,650
61-6544	B; D and G	20.2	9	2,000
63-0277	A and E	21.4	7.5	22,870
GA-5269	A and J	15.1	8.5	20,967
62-3858	B	15.9	2.5	9,000
60-1757	B and D	12	7.5	1,220
47-5465	A and J	16.8	2	38,000
GF-7248	B; C; D; G and H	9.8	< 8	6,000
59-9594	A and B	13	3.5	11,450
227-6620	A and B	25.5	3	9,292
GR-2741	D	31.9	1.8	1,450
62-4395	A	8.3	3	6,000
26-5743	A and E	23.4	2	13,905
251-2493	A; D and E	56.4	7.4	8,000
57-5315	A; C; D and E	35.7	7	9,765
252-8260	A; E and I	12	4	84,187
32-3564	E	9.9	6	5,460
GA-3048	Not Stated	17.2	4.2	20,000
250-1546	Not Stated	-	< 8	Not Stated
24-5910	Not Stated	15.6	3	Not Stated
40-8059	Not Stated	-	3	Not Stated
253-0962	Not Stated	11.2	5	Not Stated
53-6290	Not Stated	10.7	< 8	Not Stated
16-6359	Not Stated	-	< 8	Not Stated
62-7427	Not Stated	11.6	2.3	Not Stated
60-9555	Not Stated	8.4	< 8	Not Stated
251-5644	Not Stated	12.8	0.5	Not Stated
41-7187	Not Stated	13.1	4.5	Not Stated
63-2159	Not Stated	21.6	1.5	Not Stated
53-3493	Not Stated	16.9	3.9	Not Stated

Type of Repair

A: Repair of Injection Pump	F: Replacement of Silencer
B: Testing of Injectors	G: Valve Adjustments
C: Replacement of Fuel Filter	H: Replacement of Oil Filter
D: Replacement of Air Filter	I: Engine Overhaul
E: Replacement of Injector Nozzles and Testing	J: Other non-related repairs

In assessing the results of the Phase 2 program for diesel vehicles, it is apparent that significant changes are needed, both in social perceptions and in police enforcement practices if the existing smoke levels are to be brought under control. The facts that 57% of the dual-purpose vehicle owners and 65% of the bus and truck owners cited did not comply with the repair order, and that the Traffic Police were unable or unwilling to enforce such compliance, speak for themselves. A vigorous public education campaign, supported by greatly-increased enforcement efforts on the part of the Police, will be needed if the full-scale I/M program is not to be similarly ineffective.

Another suggested topic for a public education campaign is the apparent lack of any feeling of stigma or shame on the part of vehicle owners, even for vehicles that are producing grossly excessive smoke emissions. In a number of cases, grossly smoky vehicles otherwise appeared very well taken care of - clean, polished, and in free of dents or other visible damage. The owners of these vehicles clearly had the resources to maintain them in good condition, had they chosen to do so. Most people who possess the means to own a vehicle at all would feel ashamed to appear in public in one with smashed fenders, broken windows, or an exhaust system dragging on the ground. Clearly, however, many vehicle owners do not feel similarly ashamed to appear in a vehicle whose thick black exhaust conveys a similar message about the state of the engine. The number of air-conditioned (and thus relatively luxurious) buses that displayed high smoke emissions suggests that a similar lack of awareness applies to bus operators and passengers.

It is suggested that a public awareness campaign be launched to sensitize drivers and vehicle owners to the fact that heavy smoke implies poor maintenance of the engine, and to stigmatize those who thus endanger the health and safety of their fellow citizens. This campaign should dramatize the very real dangers to life and health posed by exposure to diesel exhaust. For instance, a television spot might show a schoolchild alighting from the dual-purpose vehicle bringing her home from classes, then gasping and choking as the vehicle envelops here in a black cloud on pulling off. Such a campaign might also link inadequate engine maintenance (as displayed by the high smoke levels) to inadequate maintenance of safety-related systems such as steering and brakes.

3.9.2 Two-Stroke Vehicles

3.9.2.1 Three-Wheelers

The Phase 2 emission testing and repair program for the three-wheelers was conducted from December 5 to 6, 2002 at the same location off of the High Level Road. During the two-day campaign, a total of 128 three wheelers were tested for smoke and gaseous emissions. The testing team included EF&EE staff, engineering and technical-school faculty, and motor vehicle examiners. David Pieris Company, the principal manufacturer of three-wheelers in Sri Lanka, provided a crew of mechanics and the necessary supplies to carry out on-site diagnosis and repairs to for failed vehicles.

Figure 3.19 shows a member of the testing team measuring smoke opacity from a three-wheeler. The measurement was made using the Wager 6500 smokemeters fitted with full-flow heads and

conical adapters to expand the small-diameter exhaust pipes on these vehicles to 61 mm for measurement purposes. The sensing head and the conical adapter are visible in the photo. Smoke opacity was measured both at idle and at approximately 3,500 RPM.



Figure 3.19: Measuring smoke opacity from a three-wheeler using exhaust pipe adapter

The concentrations of CO, HC, CO_2, and Oxygen in the three-wheeler exhaust were also measured at idle and 3,500 RPM, using the Horiba MEXA 554J analyzers. Figure 20 shows the sampling probe of the MEXA analyzer inserted into a three-wheeler tailpipe. Most of these tailpipes were so configured, and so obstructed by carbon, that it was not possible to insert the probe fully into the exhaust. As discussed in Section 7.3, it was determined later that this limited insertion, combined with the high levels of exhaust pulsation from these one-cylinder engines, allowed some outside air to mix with the sample, diluting it and reducing the concentrations measured. This problem was most apparent at idle.

Based on the results of the Phase 1 testing, the interim emission standards applied during the Phase 2 testing were a smoke density (K) value of 2.0, CO concentration of 4.0%, and HC concentration of 6,000 ppm. The HC and CO concentrations were not corrected for exhaust dilution, as the problem was not fully recognized (and the dilution correction was not developed) until later on. Three-wheelers that met the interim standards were released. The three-wheelers that failed the test first received on site diagnosis and repairs by the David Pieris Company mechanics.

The on-site repair parts provided by David Pieris Company included spark plugs and air filters. In addition, they provided temporary replacement carburetors and exhaust pipes to be used to confirm their diagnoses. If a vehicle were diagnosed as needing carburetor replacement, for example, the vehicle would be fitted with the temporary replacement carburetor, and the emissions would be rechecked. The original carburetor would then be put back on, and the owner would be informed that he needed to arrange for a replacement.



Figure 3.20: Sampling probe inserted into the tailpipe of a three-wheeler to measure gaseous emissions.

For testing purposes, David Pieris Company also provided a fuel tank filled with a mixture of 97% gasoline and 3% low-smoke (JASO FC grade) two-stroke oil. This is the recommended oil concentration for the Bajaj three-wheelers. Vehicles exhibiting high smoke levels due to the use of inappropriate or grades or excessive amounts of oil were re-tested after connecting the carburetor fuel line to this tank. Figure 21 shows such a retest.

The tuning and repairs performed on-site included the following:

- Replacing fuel/oil with properly premixed fuel/oil,
- Adjusting carburetor air and idling screws,
- Adjusting jet needles,
- (Temporarily) replacing carburetors,
- Replacing spark plugs, and
- (Temporarily) replacing exhaust pipes.

The repaired three-wheelers were re-tested for smoke and gaseous emissions. Information on the type of repair performed and the after-repair emission levels were recorded in data sheets. If only minor adjustments (such as adjusting air and idle screws and jet needles) were required to pass the emission standards during the retest, the vehicles were released without being cited. Those that required more significant repairs to pass, including part replacements and/or fuel replacement, were given probation notices with suggestions of the items to be repaired and serviced. After giving the probation notices, the replacement parts were removed from these three-wheelers. The owners of these three-wheelers were asked to send their vehicles for

repair/service and then retest for emissions at the RMV office. However, we received no data from any follow-up tests at RMV – suggesting that few, if any, of the vehicles cited followed through with the repairs.

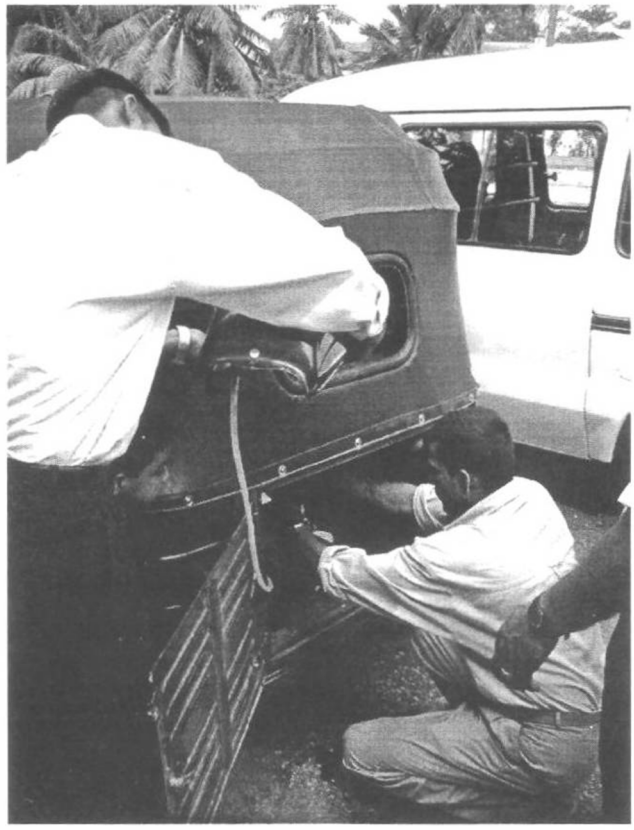


Figure 3.21: Retesting smoke opacity with a tank of correct oil-fuel mixture

The cumulative distribution graphs for three-wheeler smoke, uncorrected HC and uncorrected CO emissions are shown in Figure 3.22, Figure 3.23 and Figure 3.24, respectively. Applying the interim emission standards of 2.0 m^{-1} for smoke, 6,000 ppm HC, and 4% CO resulted in failure for 43 of the 128 three-wheelers tested, or 34%. The three-wheelers that failed for smoke were 9 (7%) at idle and 11 (9%) at 3,500 rpm. For the HC emissions, the numbers of failed three-wheelers were 24 (19%) and 13 (10%) at idle and 3,500 rpm. For the CO emissions, the numbers of failed three-wheelers were 15 (12%) and 21 (16%) at idle and 3,500 rpm.

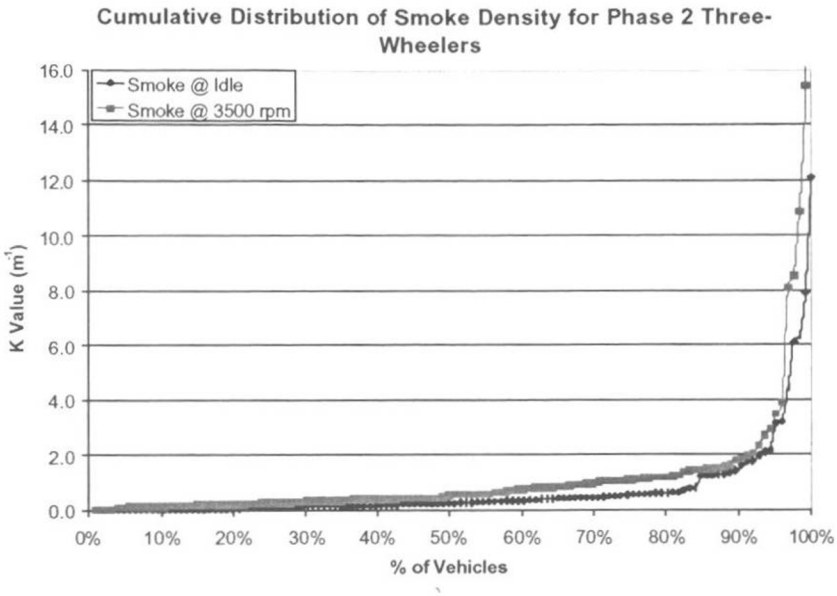


Figure 3.22: Cumulative distribution of smoke density for three-wheelers in Phase 2

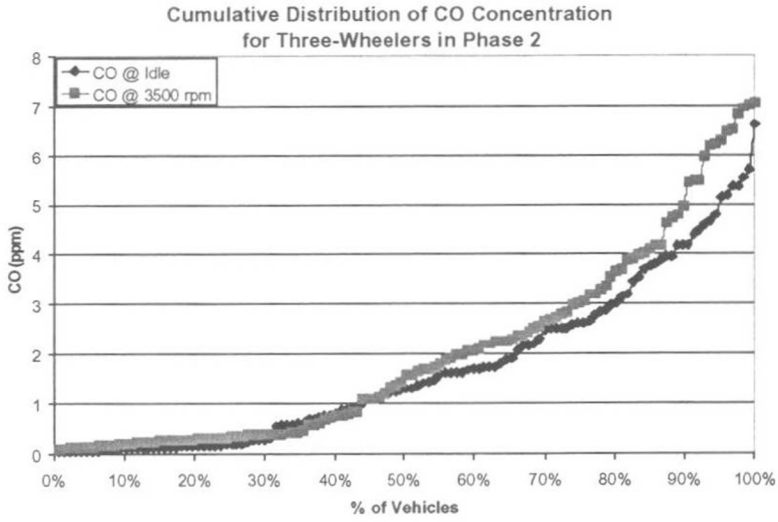


Figure 3.23: Cumulative distribution of CO concentration for three-wheelers in Phase 2 – not corrected for dilution

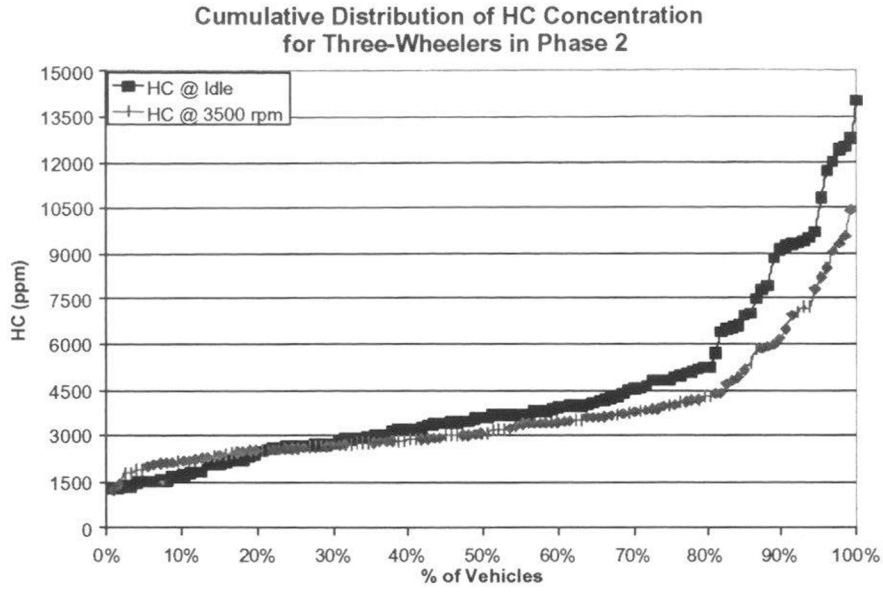


Figure 3.24: Cumulative distribution of HC concentration for three-wheelers in Phase 2 - not corrected for dilution

Most of the failed three-wheelers (22 of them) passed the emission retest with only minor carburetor adjustments. Seven of them passed when using the correct oil/fuel mixture. About 10 of them required other minor service such as spark plug replacement and cleaning the exhaust pipe, together with carburetor adjustments. Four three-wheelers would have required major repairs in order to pass the cut-points. These major repairs included two cases of high oil smoke due to faulty transmission oil seals, one case where the cylinder needed to be rebored, and one where the piston/cylinder assembly needed to be replaced.

The retest data also showed that substantial emission reductions could be achieved with proper repair and adjustment. Some of these data are tabulated in Table 3.11.

Table 3.11 : Emission data before and after repair or service for Phase 2 three-wheelers.

License Plate		Idle			3500		
		Smoke	CO	HC	Smoke	CO	HC
Carburetor Adjustment							
WP-GE-8517	Before	17.7	3.4	10175	9.3	4.9	5224
	After	3.3	2.4	6699	8.2	0.6	7555
	Reduction	81%	30%	34%	12%	87%	-45%
WP-GQ-4530	Before	1.9	4.6	6214	0.9	3.0	5051
	After	1.8	1.4	2230	5.4	0.3	2150
	Reduction	5%	70%	64%	-500%	89%	57%
206-7232	Before	0.6	4.5	6425	2.7	2.4	3368
	After	0.0	2.4	5512	3.0	0.7	3810
	Reduction	100%	46%	14%	-11%	70%	-13%
WP-GF-3362	Before	8.2	4.6	8620	2.6	6.8	5179
	After	N/A	2.4	4991	N/A	0.4	3900
	Reduction	N/A	47%	42%	N/A	94%	25%
WP-GO-7815	Before	7.5	3.9	9437	0.7	3.5	4732
	After	N/A	0.1	6118.0	N/A	N/A	N/A
	Reduction	N/A	96%	35%	N/A	N/A	N/A
WP-GJ-5051	Before	11.9	2.8	6379	19.1	0.4	4650
	After	11.7	0.5	6710	N/A	N/A	N/A
	Reduction	2%	83%	-5%	N/A	N/A	N/A
207-6775	Before	3.7	N/A	N/A	4.2	4.37	6632
	After	N/A	3.18	5608	N/A	N/A	N/A
	Reduction	N/A	N/A	N/A	N/A	N/A	N/A
Minor Service: Carb. Adj., Replace Spark Plug, 2-T Oil & Cleaned Exh. Pipe							
200-0120	Before	0.8	4.2	5896	1.6	4.5	5603
	After	0.5	0.1	6484	0.7	1.5	3441
	Reduction	38%	97%	-10%	56%	67%	39%
200-5857	Before	2.4	3.8	8635	4.7	3.4	8088
	After	N/A	3.6	7842	N/A	2.2	5152
	Reduction	N/A	5%	9%	N/A	37%	36%
207-5075	Before	7.8	4.3	8424	N/A	2.5	2808
	After	N/A	0.6	5703	N/A	2.3	4789
	Reduction	N/A	86%	32%	N/A	7%	-71%
16-7409	Before	5	4	9423	6	6	6058
	After	N/A	4	7469	N/A	4	6454
	Reduction	N/A	-9%	21%	N/A	22%	-7%
202-6478	Before	0	5.37	9310	1.1	5.5	8200
	After	N/A	1.9	3500	N/A	2.07	3952
	Reduction	N/A	65%	62%	N/A	62%	52%
Major Service: Replaced Carb., Spark Plug, 2-T Oil & Cleaned Exh. Pipe							
142-9822	Before	13.4	2.31	4630	25.5	6.02	8930
	After	14	3	3600	14	3.62	3700
	Reduction	-4%	-30%	22%	45%	40%	59%
WP-GK-0100	Before	0.8	4.0	9577	0.8	6.1	5566
	After	N/A	3.4	7019	N/A	0.7	4685
	Reduction	N/A	16%	27%	N/A	89%	16%
207-0691	Before	0.7	3.7	7024	2.3	N/A	N/A
	After	N/A	3.5	5926	N/A	1.9	4576
	Reduction	N/A	7%	16%	N/A	N/A	N/A

3.9.2.2 Two-Wheelers

The two-wheeler motorcycle campaign was conducted from December 9 to 11, 2002 at locations around Maligawatta and Kirulapana. Three motorcycle Dealers, Bajaj, Honda and Yamaha, were on-site to observe during the first day of the campaign, but no repair or service was performed on site during the first-day as the dealers did not bring any parts or tools.

Based on the emission data collected from the Phase 1 program, and confirmed during the first day of the Phase 2 campaign, Yamaha Mate motorcycles were identified as the main high smoke emitters in the motorcycle group. Subsequently, the team solicited Yamaha dealer to provide some parts for on-site repair and service, targeting these motorcycles. The Yamaha dealer responded by providing spark plugs, an exhaust muffler and some tools, and the team procured a carburetor to be used for Yamaha Mates. The next two days of the motorcycle campaign were then focused on testing and repairing/adjusting Yamaha Mate motorcycles.

During the three-day campaign, a total of 119 two-stroke motorcycles were tested for smoke and gaseous emissions. In the same way as the three-wheelers, failed vehicles that could pass the cut-points with minor carburetor adjustments were released without giving probation notices. All other failed two-wheelers were given probation notices and repair suggestions. The operators were asked to bring their vehicles back to the RMV office for emission retest after they had been repaired.

Figure 3.25, 3.26 and Figure 3.27 show the measurement of smoke levels and gaseous emissions, and the performance of roadside adjustments on two-wheelers.



Figure 3.25 : Measuring smoke opacity from a motorcycle.



Figure 3.26: Measuring gaseous emissions from a motorcycle



Figure 3.27: On-site repair/adjustment of a motorcycle

The cumulative distribution graphs for Phase 2 two-wheeler smoke, CO, and HC emission data are shown in Figure 3.28, 3.29, and Figure 3.30, respectively. With the interim cut points of 4 m^{-1} for smoke, HC of 10,000 ppm and CO of 5% (before correction for dilution), the overall number of failing vehicles were 61 or 51% of the 119 two-wheelers tested. However, most of

the failed vehicles were Yamaha Mates, due mainly to clogged exhaust pipes, and maladjusted and/or bad carburetors.

The two-wheelers that failed on smoke were 15 (13%) and 31 (26%) at idle and 3,500 rpm conditions, respectively. For the HC emissions, the numbers of failed three-wheelers were 17 (14%) and 13 (11%) at idling and 3,500 rpm, respectively. For the CO emissions, the numbers of failed three-wheelers were 15 (13%) and 38 (32%) at idling and 3,500 rpm, respectively.

The Yamaha Mate motorcycles contributed 34% (41 vehicles) of the tested two-wheelers, and about 67% of them exceeded the emission cut-points. Most of the failed vehicles (36 of them) were able to pass the interim cut-points with minor carburetor adjustments. The data also show that substantial emission reductions could be achieved with proper repairs and service. Some of these data are tabulated in Table 3.12.

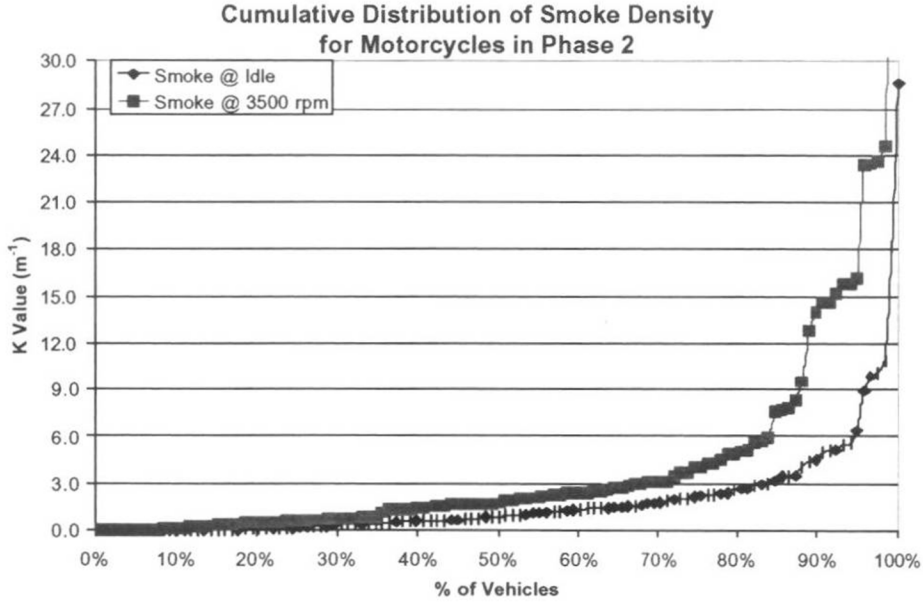


Figure 3.28: Cumulative distribution of smoke density for motorcycles in Phase 2

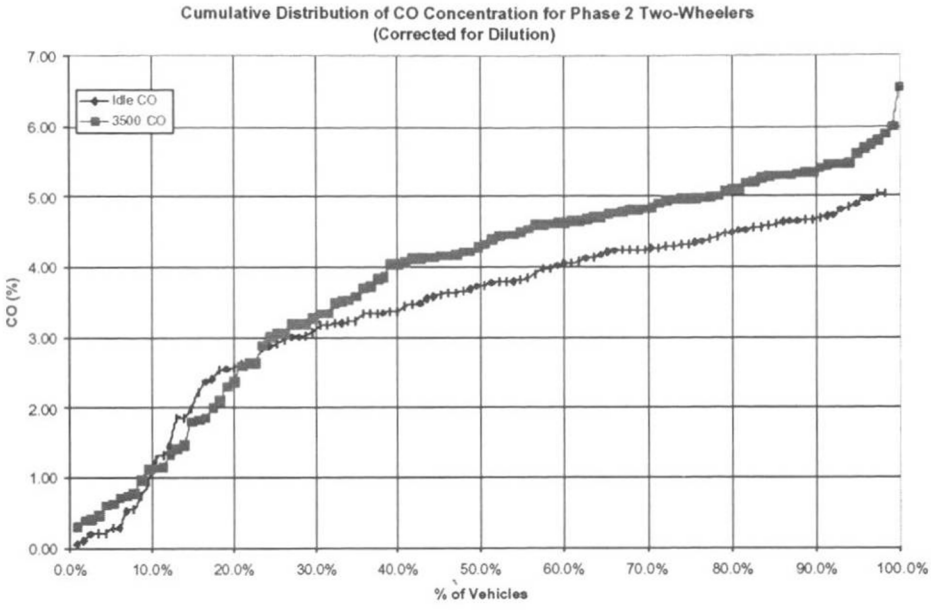


Figure 3.29: Cumulative distribution of CO concentration for motorcycles in Phase 2 (corrected for dilution)

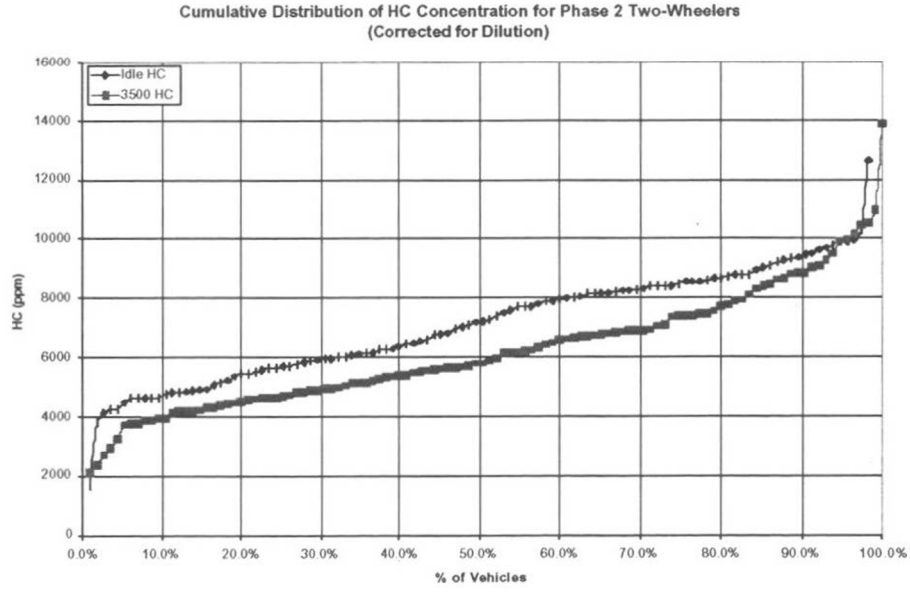


Figure 3.30: Cumulative distribution of HC concentration for motorcycles in Phase 2 (corrected for dilution)

Table 3.12 : Before and after repair/service emission data for a few Yamaha Mates.

License Plate		Idle			3500		
		Smoke	CO	HC	Smoke	CO	HC
Carburetor Adjustment							
154-5837	Before	1.1	5.33	7660	8.1	4.59	6780
	After	0	4.89	7800	2.2	3.63	6000
	Reduction	100%	8%	-2%	73%	21%	12%
139-6664	Before	17.5	6.26	10110	9.5	6.55	8800
	After	5.9	3.82	6820	2.6	4.4	5050
	Reduction	66%	39%	33%	73%	33%	43%
Replacing Spark Plug, Air Filter, Carburetor & Exhaust Pipe							
142-9822	Before	13.4	2.31	4630	25.5	6.02	8930
	After	14	3	3600	14	3.62	3700
	Reduction	-4%	-30%	22%	45%	40%	59%

3.10. PHASE 3 EMISSION TESTING: EXHAUST PIPE EXTENSION AND DILUTION CORRECTION CALCULATIONS

Subsequent to the presentation of the final report on this project, a controversy arose over the emission measurement procedure used for HC and CO concentrations of three-wheelers and motorcycles, as well as the use of the calculated dilution factor to compensate for dilution of the exhaust gas experienced in these measurements. Representatives of the principal three-wheeler vendor, Robert Peiris Company, argued that – consistent with Indian practice – an exhaust pipe extension should have been used to prevent dilution of the exhaust sample due to the pulsation effect discussed in section 3.7. It was further argued that -despite the use of the dilution correction factor – the fact that exhaust pipe extensions had not been used for the measurements in this program had resulted in these measurements being too low, and thus that emission standards recommended on the basis of these measurements were too stringent, and would result in an excessively high number of failing vehicles

To address these issues, a third round of emission tests were carried out under the direction of Dr. A.G.T. Sugathapala. A total of 201 three-wheelers and 105 motorcycles were tested between June 2 and 10, 2003. Each vehicle was tested at idle and 3500 RPM, with and without the use of an exhaust pipe extension. EF&EE personnel did not participate in performing these tests, but did carry out the analysis of the results that is presented here.

3.10.1 Analysis of Third-Phase Emission Results

Our analysis of the third-phase emission test data shows that *neither* the use of the exhaust pipe extension nor the dilution correction equation is adequate to ensure accurate results by itself. Without the exhaust pipe extension, the levels and variability of exhaust dilution experienced were such that the normal levels of error for these kinds of exhaust measurements would be expected to have a large effect on the outcome of the test. The use of the exhaust pipe extension greatly reduced the both the average and the degree of variability in exhaust dilution factors experienced, but many samples still showed a substantial degree of exhaust dilution. Therefore, we now recommend that future emission measurements include *both* the use of the exhaust extension *and* correction for dilution using the method documented.

Our analysis of the emission results concentrated on the three-wheeler data, as these were the principal focus of controversy. Dilution factors were calculated for each set of measurements using the method documented.

One three-wheeler data point taken with the exhaust extension showed a calculated dilution factor of 14, while another taken without an exhaust extension showed a dilution factor of 42. We suspect that these may have been due to data entry errors. Excluding these two doubtful values, the average dilution factor for measurements taken with the exhaust extension was 1.19 at 3500 RPM and 1.22 at idle. Individual values ranged from 1.0 (the majority, showing no dilution) up to 2.6. Thirty-four percent of the sample had dilution factors exceeding 1.2. Without the exhaust extension, the average dilution factor was 1.99 at 3500 RPM and 2.96 at idle, with individual values ranging up to 8.5. Among measurements taken with the exhaust extension, average dilution factors differed somewhat between the older 2 and 3-port engines and the newer 5-port engine design. Average dilution factors for the 5 port engines were lower at idle (1.14) but somewhat higher at 3500 RPM (1.22).

For two-wheelers, the average dilution factor with the exhaust extension was 1.20 at 3500 RPM and 1.34 at idle, with individual values as high as 4.5. Without the exhaust extension, it was 1.75 at 3500 RPM and 2.18 at idle, with individual values as high as 10.

The OIML standard allows a level of error in HC and CO emission measurements up to 5% of the reading. With these high levels of dilution, a relatively small error in the measurement of emission concentrations can have relatively large effect on the result – especially as these errors will affect both the emission concentration that is multiplied by the dilution factor and the calculation of the dilution factor itself. The use of the exhaust extension greatly reduced the average dilution factors and the range of variability in dilution factor between vehicles, thus reducing the scope for such errors to affect the final result.

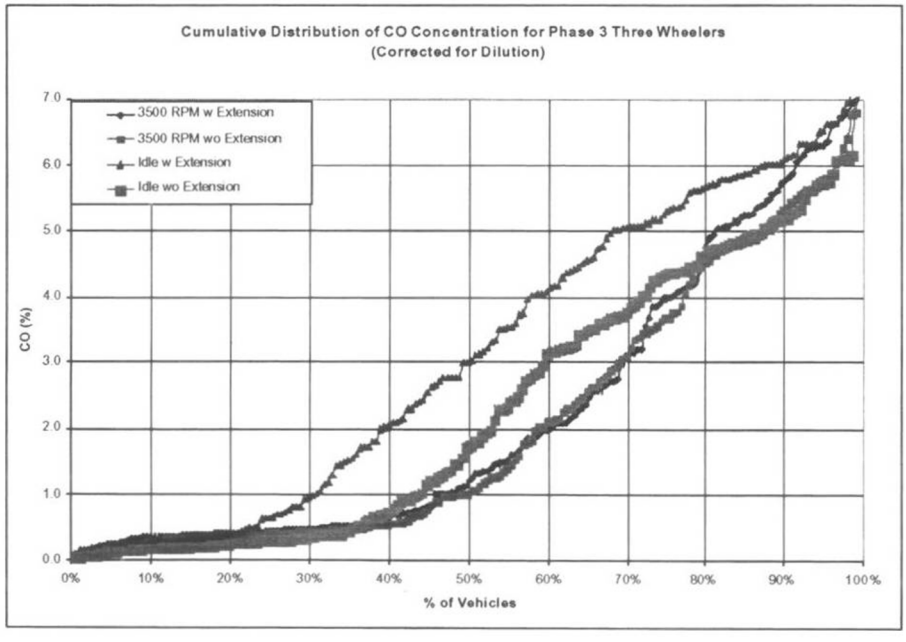


Figure 3.31: Cumulative distribution of CO concentrations for three-wheelers with and without exhaust pipe extension (corrected for dilution).

Figure 3.31 and 3.32 show the cumulative distributions of CO and HC emission measurements for the three-wheelers tested in Phase 3. As these data show, the emissions data taken with the exhaust pipe extension show generally higher CO and HC concentrations at idle than without the extension. At 3500 RPM, the difference is less marked, but still visible. This suggests that the dilution factor calculation may be under-correcting for actual dilution levels at idle. An alternative explanation is that the higher HC and CO concentrations could be artifacts due to the extension pipe, but we consider this unlikely.

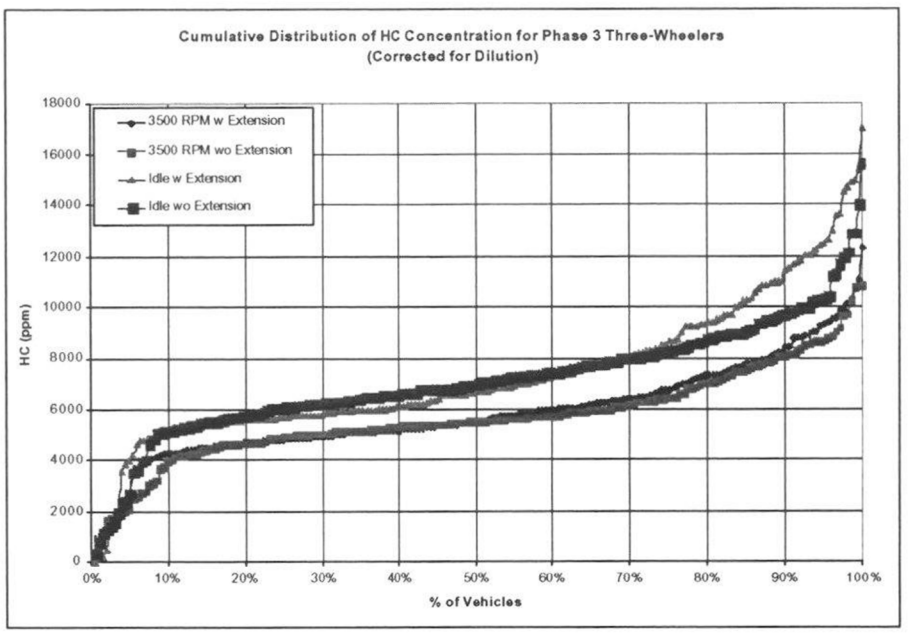


Figure 3.32: Cumulative distribution of HC concentrations for three-wheelers with and without exhaust pipe extension (corrected for dilution).

The effects of the dilution correction on the cumulative distributions of CO and HC emissions are shown in Figure 3.33 and 3.34, respectively. These graphs compare the cumulative distributions of the dilution-corrected pollutant concentrations to the corresponding cumulative distributions for the pollutant concentrations without correction. As expected, the concentration values are modestly higher after the correction. Thus, a higher percentage of vehicles would be expected to fail any given emission standard if the dilution correction were in force. Since dilution factors up to 2.6 were observed even with the exhaust extension in use, the effect on results for a specific vehicle could be much greater than the relatively small differences shown in these plots.

The cumulative distributions for exhaust CO and HC concentrations of the motorcycles tested in Phase 3 are shown in Figure 3.35 and 3.36, respectively. These data were taken both with and without the extension pipe, and have been corrected for dilution. In general, the motorcycle data show less effect from the exhaust extension than do the three-wheeler data.

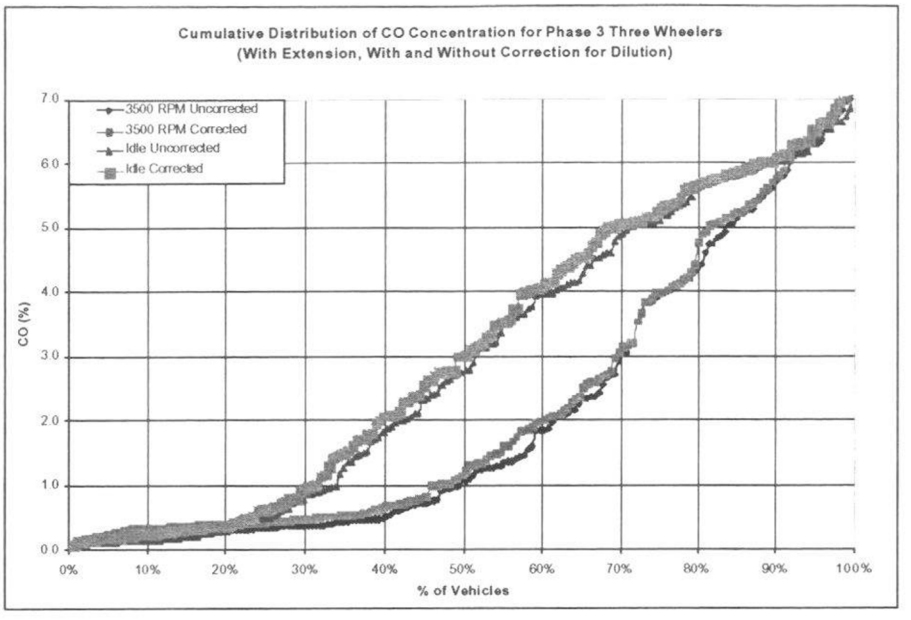


Figure 3.33: Cumulative distribution of CO concentrations for three-wheelers with exhaust pipe extension – effect of correcting for dilution.

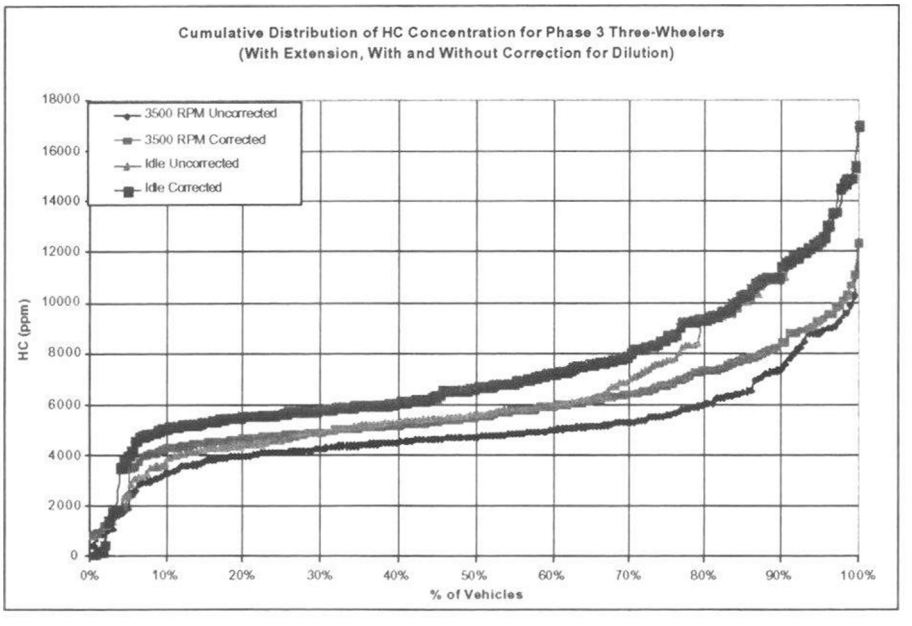


Figure 3.34: Cumulative distribution of HC concentrations for three-wheelers with exhaust pipe extension -- effect of correcting for dilution.

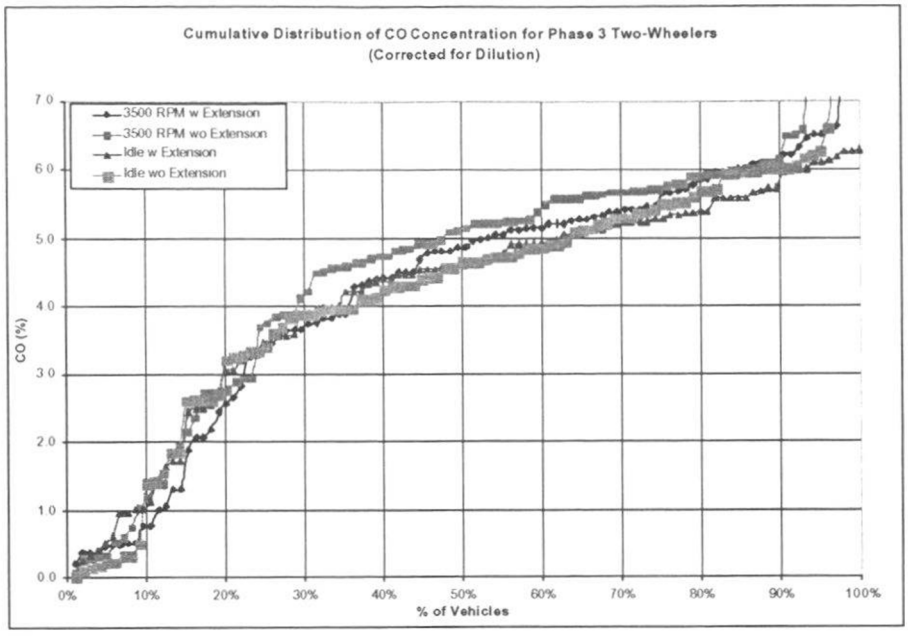


Figure 3.35: Cumulative distribution of CO concentrations for motorcycles with and without exhaust pipe extension (corrected for dilution).

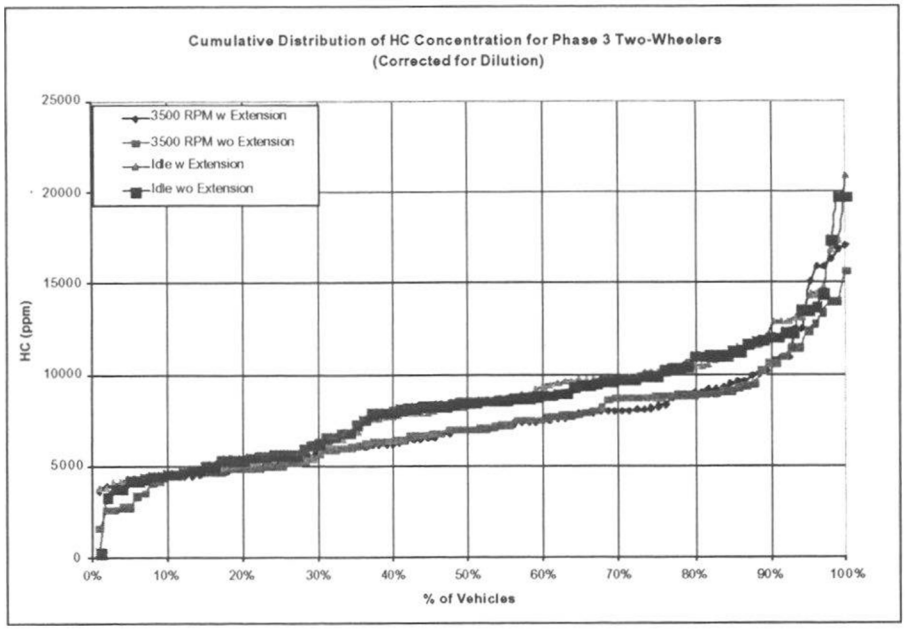


Figure 3.36: Cumulative distribution of HC concentrations for motorcycles with and without exhaust pipe extension (corrected for dilution).

3.10.2 Recommended Emission Standards

The effects of recommended emission standards developed in Section 8 for three-wheelers and motorcycles were re-examined using the emissions data from Phase 3. Based on the data obtained in Phase 1, we formerly recommended emission standards for three-wheelers of 7500 ppm HC and 5.0 percent CO, after correction for dilution. These were estimated to result in failure rates of 23% for HC and 18% for CO. Thirty-three percent of three-wheelers were expected to fail either or both standards. Applying the same standards to the three-wheeler results obtained with the exhaust extension shows that - if the results are *not* corrected for dilution - then 29% would be expected to fail for HC and 32% for CO, with a combined failure rate of 34% (in other words, most HC failures also fail CO). This overall failure rate is slightly higher than was estimated in our earlier report, based on the Phase 1 data.

If -- as we recommend -- the Phase 3 data *are* corrected for dilution, then the failure rate at the emission standards that we formerly recommended would rise to 51%, with 44% failing for HC and 36% for CO. To reduce the failure rate to the level formerly estimated would require relaxing the standards to 9000 ppm for HC and 6.0% for CO. This would result in an overall gaseous emissions failure rate of 32%, with 27% failing for HC and 18% for CO. We therefore recommend that these standards be adopted be for three-wheelers, together with the requirement that the measured concentrations be corrected for dilution.

With respect to motorcycles, the emission standards recommended in our earlier report were 12,000 ppm HC and 6% CO, and these were expected to result in failure rates of 10% for HC and 14% for CO, with 21% of motorcycles failing for HC, CO, or both. Analysis of the Phase 3 data shows that the application of these standards, together with the exhaust pipe extension and correcting for dilution would result in a combined gaseous emissions failure rate of 29%, with 20% failing for CO and only 11% for HC. We consider these results reasonable, and recommend no change to the proposed motorcycle standards.

3.11. I/M PROGRAM DESIGN AND IMPLEMENTATION

This chapter presents our recommendations for the design and implementation of the vehicle I/M program to be established in Sri Lanka. This includes our recommendations concerning the overall design of the program or "system architecture", the emission standards and test procedures, the requirements for vehicle inspection facilities, program supervision and oversight, and implementation of on-road inspections.

While the present study has established a firm foundation for the implementation of such a program, much work remains to be done. Given the limited capacity and experience both of the Government agencies responsible for implementing the program and the private garages needed to carry out the repairs, we recommend that the program be implemented in phases. The suggested work program and schedule are also presented in this section.

3.11.1 I/M System Architecture

The issues involved in I/M program design were discussed in serction 3.5. In our opinion, the following key features are *required* for a vehicle I/M program to be effective in Sri Lanka, or in any other developing nation:

- The I/M program should comprise periodic inspections supplemented by on-road enforcement of emission standards with the aid of the Traffic Police.
- Periodic inspections should be carried out *only* in a limited number of high-volume, centralized, test-only inspection stations linked to a central vehicle inspection database. These inspection stations should be established and operated by private firms under Government supervision and oversight. They should be equipped with chassis dynamometers (at least for diesel vehicles) and computerized emission analyzer systems to minimize the potential for inspection personnel to affect the test results.
- Compliance with the I/M program requirements should be enforced both through the vehicle registration process (a vehicle that has not passed inspection will not be allowed to re-register) and through the use of counterfeit-resistant window stickers indicating the date by which the next inspection must be passed. It should be illegal to park or operate a motor vehicle without a valid sticker on the public roads in designated "critical air quality areas" such as the Galle - Colombo - Negombo corridor. For reasons of cost-effectiveness, as well as practicality of implementation, the sticker requirement should not apply in rural areas far from urban centers. To avoid the problem of urban vehicles re-registering in such areas, however, the requirement *should* apply to rural vehicles and long-distance transport vehicles when operating in critical air quality areas. To accommodate infrequent visitors, four-stroke petrol vehicles could be allowed to purchase a "visitor pass" - valid for a limited time - *en lieu* of obtaining an inspection sticker.

- Government should contract with a suitably qualified company or organization to provide technical support and assist in supervising the I/M program. This organization would maintain master calibration standards; monitor and analyze the inspection results submitted by the inspection stations; carry out overt and covert audits of I/M station performance to verify the accuracy, repeatability, and honesty of inspections; and provide the analyzers and personnel for on-road emissions checks in cooperation with the Traffic Police. It should also review the I/M emissions standards and failure rates on an annual basis, and recommend appropriate tightening of standards as the average level of vehicle emissions goes down.
- The capital and operating costs of the I/M program should be recovered through a fee paid by the vehicle owner to the inspection station. The costs of Government supervision and oversight, including the cost of the technical support contractor, should be recovered as part of this fee.

3.11.1.1 Vehicle Inspection Procedures and Emission Standards

We recommend that the emission test for diesel vehicles comprise measurement of smoke opacity at full load and at half load on a chassis dynamometer, as well as the snap acceleration test described in SAE Recommended Practice J1667. As discussed in section 3.5, and borne out by our experience during the pilot I/M program, the snap acceleration test is highly useful for on-road emission checks, but it is not – by itself – an adequate basis for a periodic vehicle emission inspection program. Because the severity of the test depends on the rapidity with which the engine accelerates, the snap acceleration test can be defeated fairly readily through measures (such as installing a throttle delay, or bribing the test technician to depress the pedal slowly) that have little or no effect on real on-road PM emissions. It is still worth including in the I/M test procedure, however, as a check on transient smoke opacity from turbocharged engines and as a point of comparison for on-road emission checks.

The recommended emission standards for smoke density from existing vehicles in the first years of the I/M program are 8.0 m^{-1} in the snap acceleration test and at full load, and 5.0 m^{-1} at part load on the chassis dynamometer. As outlined in section 3.8, the 8.0 m^{-1} standard for smoke would give an initial failure rate of about 20% for heavy-duty trucks and buses, and 40% for light-duty diesel vehicles. The addition of the full-load emission test would increase the failure rate still further, but these additional failures could readily be corrected (or prevented) by changing the air filter and/or adjusting the maximum fuel stop on the injection pump to the correct setting. The half-load emission standard is not expected to increase the initial failure rate significantly, but would make the test more difficult to defeat, and would help to ensure that emission repairs actually address the root of the problem.

Emission tests for petrol vehicles should include measurement of smoke opacity, HC concentration, and CO concentration. These should be measured at idle and at intermediate speed under no load. The intermediate speed test should be conducted at 3500 RPM for motorcycles and 3-wheelers and at 2500 RPM for cars and trucks. For existing vehicles, the recommended emission standards for gaseous pollutants are: 9000 ppm HC and 6.0% CO for three-wheelers; 12000 ppm HC and 6.0% CO for motorcycles; and 1000 ppm HC and 6.0% CO for cars and trucks, after correcting for dilution in each case. Three-wheelers and

motorcycles should be tested using an exhaust pipe extension to reduce exhaust dilution due to the pulsations in the exhaust.

The recommended limits for smoke density (K value) are 2.0 m^{-1} for three-wheelers, cars, and trucks, and 4.0 m^{-1} for motorcycles. The smoke density limit for petrol cars and trucks is expected to produce a very low failure rate, but will serve to identify the minority of vehicles that do exhibit high smoke emissions due to oil leaking into the combustion chamber or into the exhaust. To ignore such vehicles while cracking down on excessive smoke emissions from two-stroke engines would certainly be perceived as unfair.

Vehicles that are imported subject to the emission standards discussed in section 3.3 are capable of meeting much more stringent emission standards than those recommended above. For diesel vehicles at the time of import, we recommend applying the smoke standards established in the applicable E.U. regulations. For Euro 2 vehicles, the applicable limits are set by ECE regulation R24.03, with K value limits ranging from 1.065 m^{-1} to 2.26 m^{-1} depending on engine displacement. The smoke density limits in snap acceleration are 0.5 m^{-1} higher than the corresponding full-load values. In-use emission limits of 2.5 m^{-1} for naturally aspirated engines and 3.0 m^{-1} for turbocharged engines have been established in several European countries; and similar limits could appropriately be applied to vehicles imported to Sri Lanka after the Euro 2 requirements go into effect.

Petrol vehicle that meet the Euro 2 and later standards will generally be equipped with electronic fuel injection systems and three-way catalytic converters. Appropriate I/M concentration limits for these vehicles would be 1.2% CO and 220 ppm HC. It would be appropriate to establish NOx emission limits for these vehicles as well, to ensure that they are not tuned "lean" just to pass the emission test.

Emission control systems for electronically fuel injected vehicles are usually very reliable, so that it is not necessary to inspect these vehicles every year. We recommend that vehicles equipped with this type of engine be inspected upon their first importation to Sri Lanka, and then every three years until they are nine years old. After that, they should be inspected every year.

3.11.1.2 Vehicle Inspection facilities

The capacity of a vehicle inspection program can be expressed in terms of the number of vehicle inspection "lanes" required to perform the required emission tests. As Table 3.13 shows, a single vehicle inspection lane has the capacity to process about 25,000 vehicles per year, working two shifts per day with one hour at the beginning and end of the day for startup and shutdown. Because demand for inspections is not uniform with time, the actual number of vehicles that one lane can inspect without experiencing unacceptably long queues at peak times is about 60% of this number. Efficiency of utilization can be improved, and the need for queueing can be minimized, by taking appointments.

Table 3.13: Estimated vehicle throughput per inspection lane

Vehicle Inspections per Lane per Year	
Inspection time (minutes/veh)	10
Hours of inspections/day	14
Days inspections/year	300
Total inspection capacity/year	25,200
Capacity factor	60%
Actual Vehicles/lane-year	15,120

Assuming an actual, practical throughput of 15,000 vehicles per year, about 129 inspection lanes would be needed for an island-wide I/M program. If the program were to apply only in the Galle-Colombo-Negombo corridor, then we estimate that only about half of the light-duty vehicles and three-quarters of the heavy-duty vehicles would find it necessary to undergo inspection, requiring a total of 67 test lanes. The breakdown of test lanes required by vehicle type is shown in Table 3.14. Not all of these inspection facilities would be needed at once, however. As discussed in section 3.11.4, we recommend phasing in the I/M program over several years, so that only about 20 inspection lanes (15 for diesel light-duty vehicles, and five for three-wheelers) would be needed in the first year of the program. Adding heavy-duty diesel vehicles and two-stroke motorcycles during the second year of the program would increase these numbers by six heavy-duty and 11 motorcycle inspection lanes.

Table 3.14: Number of test lanes needed by vehicle type

Vehicle Class	2005 Fleet	Insp/ Veh-Year	Est Failure Rate	Total Insp/Year		Test Lanes Needed	
				Islandwide	WP Only	Islandwide	WP Only
Diesel Lorries and Buses	102,970	1	25%	128,713	96,534	9	6
Diesel Pass Cars and DP	300,457	1	50%	450,686	225,343	30	15
Diesel 3-Wheel	4,719	1	50%	7,078	3,539	0	0
Petrol 4-Wheel	229,730	1	25%	287,163	143,581	19	9
Petrol 3-Wheel	93,956	1	50%	140,935	70,467	9	5
Motorcycle - 4T	479,745	1	25%	599,681	299,841	40	20
Motorcycle - 2T	227,332	1	50%	340,999	170,499	23	11
Total	**1,438,910**			**1,955,254**	**1,009,805**	**129**	**67**

A single inspection facility may contain as few as one or as many 10 or more individual inspection lanes, depending on the demand for inspections in the area. Given the modest vehicle fleet size in Sri Lanka, we anticipate that most light-duty inspection facilities would contain between two and four inspection lanes, while heavy-duty facilities would contain one or at most two lanes. Thus, recommended first-year I/M program would thus require about seven to 10 light-duty inspection facilities; by the second year, about 10 to 15 light-duty and 4 to 6 heavy-duty facilities would be needed. A fully-developed I/M program covering all vehicles in the Galle-Colombo-Negombo corridor would require about 20 light-duty inspection facilities and four to six facilities for heavy-duty vehicles.

Equipment requirements for an inspection lane include a light-duty or heavy-duty chassis dynamometer, smoke meter, four-gas analyzer, and an automated emission measurement and recording system linked to a central database. The inspection lanes should be housed in a purpose-designed building, with vehicle traffic arranged to flow from one side of the building to the other as shown in Figure 3.37. Vehicle data are collected at one station at the front of the lane. The driver gets out of the vehicle at this point, then the test technician drives it to a second station for the actual emission test. Test results are given to the driver at a third station at the exit from the building. If the vehicle passes the test, the technician at this station affixes the "passed" sticker to the windshield.



Figure 3.37: A typical vehicle inspection facility in Mexico City

Ventilation arrangements for I/M facilities require special attention to protect the inspectors from unhealthy pollutant concentrations. Inspection lanes for heavy-duty diesel vehicles require heavy-duty chassis dynamometers, high-volume ventilation equipment, and adequate space for maneuvering of large vehicles. We recommend that these be separated from the inspection facilities for smaller vehicles.

3.11.1.3 On-Road Checks

On-road enforcement and roadside checking of vehicle emissions are important elements of a comprehensive I/M program. On-road checks could be conducted by the Traffic Police in the course of their normal duties. Only minimal training would be required to enable these policemen to identify visually and cite vehicles having grossly excessive smoke emissions. To limit the effects of possible errors and subjectivity, we suggest that motorist should not be fined on the basis of a visual smoke assessment alone. Instead, the Policeman could require the vehicle to undergo an emissions inspection using a smokemeter – either at an emission test facility or at the nearest police station or smoke checkpoint.

In addition to this widespread visual enforcement against excessive smoke emissions, we suggest that roadside checks using smokemeters, and (for petrol vehicles) emission analyzers be conducted on a "spot check" basis at randomly selected locations in critical air quality zones. These on-road checks are valuable both for their direct value in identifying high-emitting vehicles and as an independent check on the effectiveness of the periodic I/M program. We suggest that these activities be performed jointly by the Traffic Police and the I/M program's quality assurance contractor. Contractor personnel would perform the actual emission tests, while the Police would focus on stopping vehicles and issuing citations. The use of proper equipment and adequately trained operators will help to assure that the resulting emission measurements are accurate, while the presence of personnel from two different organization will help to deter corruption - often a major issue with such programs. Further deterrence can be achieved by rotating the officers and the emission testing crews frequently, so that the same group does not work together week after week.

3.11.1.4 Program Enforcement

A vehicle I/M program will be ineffective if motorists are not made to comply with its requirements. It is important that the program be enforced effectively from the beginning - otherwise, motorists will quickly learn that they can safely ignore it, and it will be far more difficult to institute effective enforcement later on. The poor compliance rate observed with the pilot I/M program suggests that the program may already be facing an uphill battle in this regard.

Compliance with the I/M requirement should be enforced through two principal mechanisms: window stickers and the vehicle taxation process. The window sticker should be affixed to each vehicle as it passes inspection. These stickers should be of a counterfeit-resistant design, and should be serially numbered. The serial number of each sticker issued should be associated with the vehicle's identifying data in the central I/M database. This database should be accessible to the Traffic Police, to enable them to determine whether the vehicle that now displays a given sticker is the one to which that sticker was issued. This will be an important factor in detecting counterfeit stickers and prosecuting those who produce and use them.

To reduce the burden on the public, we recommend that enforcement of the I/M requirement be limited to vehicles that are registered or operate in a declared "critical air quality zone" such as the Galle-Colombo-Negombo urban corridor (and any other cities determined to have significant vehicle emission problems). This would effectively exempt many vehicles - especially motorcycles - that operate exclusively in rural areas, and thus have little impact on urban air quality. Compliance would be especially burdensome for such vehicles, since they seldom or never travel to towns where they could undergo the inspection. On the other hand, vehicles that *do* travel to critical air quality zones should be required to comply with the I/M program by displaying a valid inspection sticker while operating in the critical air quality zone. Otherwise, if out-of-area vehicles were allowed to operate *without* displaying a valid sticker, it would be much more difficult for the police to enforce the sticker requirement. Owners of vehicles domiciled in the critical air quality zone would be able to evade the I/M requirement by re-registering their vehicles in rural areas. The result would be a serious degradation the efficiency and fairness of the program.

An exemption to the sticker requirement could possibly be made for light-duty petrol vehicles and motorcycles that visit the urban area only infrequently - allowing them to purchase a pass good for a few days *en lieu* of a sticker. We recommend against allowing such passes for diesel or commercial vehicles, however, as they would inevitably be subject to abuse.

Each window sticker should clearly indicate the month and year that it expires, in such a manner that it can easily be checked by the Traffic Police. (For example, color coding could be used to indicate the year). Driving or parking a vehicle, or causing it to be driven or parked in the critical air quality zone without a valid sticker would be an offence subject to a fine. Non-complying vehicles should also be required to pass the I/M inspection. To even out the load on the inspection stations, we recommend that roughly equal numbers of vehicles be scheduled to undergo inspection in each month of the year.

It will also be important to ensure that the Traffic Police give adequate priority to enforcing the sticker requirement. This may require that a certain number of new positions be created in the police force for this purpose. Funding for these positions, as well as for traffic officers assigned to on-road emission checks, could come from part of the fee charged to the motorist for the compliance sticker.

Counterfeiting of stickers is a common problem in sticker-enforced I/M systems, and is difficult for the policeman to detect. For this reason, we recommend enforcement through the vehicle registration/taxation process as well. At the time that the year's tax is paid, the clerk should check that the serial number of the emissions compliance sticker matches the data recorded for that vehicle in the I/M database. This will require that the clerks have real-time access to the database by means of a suitable data terminal. The costs of this access could also be paid from part of the fees charged by the Government for the stickers.

3.11.1.5 Quality Assurance and Oversight

Adequate quality assurance and oversight of the I/M inspection facilities are essential to a fair and effective I/M program. As the authority responsible for authorizing the I/M facilities, Government must also take responsibility for policing them. While it has the ultimate responsibility, however, the Sri Lankan Government presently lacks the equipment and trained personnel needed to establish and maintain an effective oversight program using its own forces. We therefore recommend that most of the technical aspects of this oversight be contracted to a suitable private firm, or to a suitable non-governmental organization that possesses the technical skills to do the job effectively.

As discussed in section 3.5.1.3, the quality assurance and oversight contractor should take on the key technical responsibilities for the I/M system. These include:

- setting up and administering the I/M database, together with the real-time links to inspection facilities and district offices, and preparing periodic analyses and summaries of inspection statistics;
- maintaining primary calibration standards, verifying the skills of inspection personnel, and performing overt audits of I/M facility operation to assure accuracy and repeatability from test to test and station to station;

- preparing undercover vehicles and providing technical support for covert audits of I/M facilities (in cooperation with the responsible law enforcement agencies) to check that inspections are being performed honestly;
- tracking and auditing the manufacture, distribution, and issue of emissions compliance stickers, and maintaining a database of valid stickers for reference by police and motor vehicle examiners;
- providing emission measurement equipment and personnel to support on-road vehicle emissions checks by the Traffic Police on a continuing basis;
- reviewing and recommending revisions to the applicable emission standards as the highest-emitting vehicles are gradually removed from the fleet, and as lower-emitting advanced technology vehicles increase in numbers. In this way, the average emission levels of the vehicle fleet can be reduced substantially over a period of five to seven years;
- providing technical support and advice to Government on emissions issues for newly-imported vehicles, including the equivalency of different national or international standards, and whether specific vehicles or groups of vehicles comply; and
- carrying out special studies and investigations as needed in the area of vehicle emissions, including studies to evaluate improved inspection methods and equipment.

The resulting organization would thus serve the Government as a readily-accessible reservoir of technical knowledge and experience in the area of vehicle emissions. It is recommended that these activities also be funded through the fees charged for the emission stickers.

3.11.2 Program Costs and Funding

The costs to set up and operate the vehicle I/M program can be divided into the costs to the Government for supervision and oversight, and the costs to private investors to build and operate the vehicle inspection centers. Both of these costs should ultimately be paid by the vehicle owners, under the "polluter pays" principle.

The approximate costs to build and operate one vehicle inspection lane for heavy-duty or for light-duty vehicles are shown in Table 3.15. The cost estimates for the light-duty lane assume that the lane is part of a multi-lane facility - costs for a stand-alone inspection lane would be somewhat more. The costs for the heavy-duty test lane assume a stand-alone facility, as our calculations indicate that only nine such lanes would be needed island-wide. The total annual revenue required to pay the operating costs and return an attractive profit on the capital investment come to about USD 135,000 per heavy-duty test lane, and USD 103,000 per lane for light-duty vehicles. To generate this revenue, the test fees to the vehicle owner would need to be about Rs 1000 for heavy-duty vehicles and Rs 600 for light-duty vehicles.

Table 3.15: Estimated costs to build and operate a vehicle inspection lane

	Heavy Duty	Light Duty
Capital Cost (USD)		
Chassis Dyno	50,000	30,000
Smokemeters / Analyzers	6,000	10,000
Informatics	20,000	10,000
Building	80,000	30,000
Installation	20,000	10,000
Training and Startup	30,000	30,000
Total Capital Costs	206,000	120,000
Amortized 5 years @20%	30,900	18,000
Annual Operating Costs (USD)		
Labor	55,000	45,000
Utilities and Misc.	20,000	10,000
Land Rent	30,000	10,000
Total Operating Costs	105,000	65,000
Revenue Required		
Total Revenue Required	149,490	91,300
Vehicles Inspected/Year	15,120	15,120
Inspection Fee Required	9.89	6.04
Inspection Fee Rs	989	604

Table 3.16: Estimated oversight and supervision costs for the vehicle I/M program

Oversight Component	Capital Cost	Operating Cost/Year
Central I/M database & comm.	2,000,000	600,000
Overt QA	25,000	200,000
Covert audits	350,000	400,000
On-road testing support (10 teams)	300,000	400,000
Evaluation and assessment	500,000	200,000
Sticker Production/Security	25,000	300,000
Total Cost	3,200,000	2,100,000
Total Revenue Required		2,944,152
Vehicles Covered		1,000,000
Sticker Cost / Vehicle USD		2.94
Sticker Cost / Vehicle Rs		294

In addition to the test fee to the inspection facility, vehicle owners would pay a fee for the emissions compliance sticker itself. These fees would go to pay for program supervision and oversight. Some very rough estimates of the supervision and oversight costs of an island-wide I/M program covering one million vehicles are shown in Table 3.16. The resulting sticker cost would amount to about Rs 300 per vehicle per year. Since startup costs will be higher, and the

number of vehicles covered will be lower during the first years of the program, we recommend that the sticker fee initially be set at a higher level, such as Rs 500. This will help to ensure that the program has the revenue needed to get off to a good start.

3.11.3 Training Requirements

Training will be required for I/M inspection personnel to carry out the inspections and for vehicle mechanics to perform the repairs. Less extensive training will also be needed for Department of Motor Traffic vehicle examiners and the Traffic Police to enable them to carry out their parts in the enforcement program. We recommend that the each I/M inspection contractor be responsible for the training of its own personnel, following guidelines to be developed by the technical support contractor. Under direction from AirMac, the technical support contractor should also take direct responsibility for training of motor vehicle examiners and traffic policemen.

Training of vehicle mechanics should not require any new programs. Substantial training programs for vehicle mechanics are already in operation, and the results of these programs appear satisfactory. The know required to incorporate emission inspections and repair into these training programs has already been transferred to a cadre of technical school teachers through their involvement in this program. Experienced diesel mechanics already know nearly all that they need to know to carry out emission-related repairs, and can readily learn the rest. As the I/M program approaches reality, it can be expected to generate substantial market demand for vehicle emissions repair training, and for journeyman and apprentice repair technicians who have received such training. Assuming the vehicle populations and failure rates shown in Table 3.14, the resulting repairs would keep about 400 mechanics busy during the first year. The existing technical schools should be capable of fulfilling this demand.

3.11.4 Phase in Schedule

Given the magnitude of the task, the limited experience with vehicle I/M in Sri Lanka, the limited capacity of the vehicle repair industry, and the shortage of technical resources available, we strongly recommend that the periodic vehicle inspection program should not be implemented all at once. Instead, it should be implemented in phases, with priority being given to the vehicles and geographic areas that are of greatest concern. By confining the initial periodic inspection program to a limited geographic area and only a few classes of vehicles, the difficulties and risks involved in program implementation can be reduced significantly. As the program develops, it can then build on the experience and public acceptance gained with the initial program. This will also help to reduce the risk perceived by private investors in the vehicle inspection centers, and thus to reduce the return on capital that they demand for their investment. That will help to reduce the long-term costs of the program significantly.

In our view, the geographic area of greatest concern from a vehicle emissions standpoint is the urbanized region of the Western Province, comprising the Colombo metropolitan area and the associated urbanized region along the coast from Negombo to Galle. This region accounts of about half of all the vehicle registrations in Sri Lanka, and probably for an even larger fraction

of the vehicle traffic, due to Colombo's role as the principal port and transportation center for the island.

Of the different vehicle classes, light-duty diesel vehicles are clearly the class of greatest concern, given their numbers and the extremely high levels of smoke emissions that many of them display. Second priority should be given to heavy-duty diesel trucks and buses. To avoid overloading the diesel engine repair capacity of the country, we recommend that the inspection of diesel trucks and buses be scheduled to begin approximately 12 months after beginning inspection of light-duty diesel vehicles.

Among petrol vehicles, we recommend assigning first priority for inspection to three-wheelers, since these tend to be intensively used, and the great majority of them are equipped with high-emitting two-stroke engines. Since the technical resources required for three-wheeler repair are largely separate from those required for diesel repair, these inspections could begin at the same time as the inspection of light-duty diesel vehicles. The next priority would go to two-stroke motorcycles, followed by passenger-cars and other four-wheel vehicles, and finally four-stroke motorcycles. Vehicles using LPG and other alternative fuels should be subject to the same inspection schedule as comparable petrol vehicles.

A reasonable phase-in schedule for the I/M program would thus be as follows:

Year 1 - light-duty diesels and three-wheelers

Year 2 - heavy-duty trucks and buses and two-stroke motorcycles

Year 3 - Petrol vehicles (including motorcycles) with four-stroke engines

To avoid overloading the vehicle repair industry, we recommend that on-road emissions enforcement activities be phased in as well. It is suggested that the Traffic Police begin by citing only the most egregiously smoky vehicles (whether diesel or petrol-fueled), and then gradually increase the enforcement severity until the smoke opacity standards are being strictly enforced. At that point, limited on-road checks of CO and HC emissions could be implemented as well to check on the effectiveness of the periodic I/M inspections.

3.11.5 Next Steps and Timetable for Establishing an I/M Program

The present study has laid a firm foundation for the development of a vehicle I/M program, but a number of steps remain to be accomplished before such a program could begin operation. The key steps remaining in the process are the following:

Develop consensus and finalize I/M program design - AirMac and the Department of Motor Traffic should take the lead to develop consensus within the Government on the desired I/M program design and phasing. This consensus should include agreement on the types of vehicles to be subjected to the I/M program in the first phases, the geographic area to be covered, and the basic design of the I/M program - including the strategy to establish relatively lenient standards initially and then tighten these over time. It should also be confirmed that the desired structure is compatible with existing law. Any changes needed in existing law or regulation should be identified and initiated. Estimates should be developed of the size of the vehicle fleet affected and the number of I/M facilities required, based on the specific geographic coverage

proposed for the program. Detailed test protocols should be prepared in algorithmic form, suitable for implementation in computer software. Specifications should be developed for the central I/M database and for the data communications links between this database and the I/M stations, in sufficient detail that these can be included in the bidding documents. (6 months, if no new legislation is needed)

1. Prepare bidding documents - Once consensus is achieved on the overall design, AirMac should draft the solicitation documents for authorized vehicle inspection centers and for the technical support contractor to provide system oversight and supervision. These should be developed in close consultation with the Department of Motor Traffic, and with the assistance of expert consultants. The documents should then be subjected to legal and policy review. We recommend that the initial solicitations cover inspection of light-duty diesel vehicles and two-stroke three-wheelers; as well as the technical support required for program supervision and oversight. In practice, the drafting of the solicitation and the finalization of I/M program design will likely proceed in parallel, as some issues and differences of opinion may not be apparent until the technical requirements and evaluation criteria are written down. It is also recommended that a conference be held with potential bidders prior to finalizing the solicitation documents, as this may help to prevent misunderstandings and to increase the response to the final solicitation. (3 months).
2. Develop proposals - Bidders respond to the solicitation documents, preparing and submitting proposals for the construction and operation of the inspection centers, and for the required technical support for the central database, supervision, and oversight functions. (2 months).
3. Proposal evaluation and selection - The responses are evaluated, and the successful proposers are notified of their selection. (2 months). At this point, the Government could begin preparation of bidding documents for the second phase.
4. Construction and preparation - The successful proposers construct and equip the vehicle inspection centers. At the same time, the technical support contractor constructs and equips the I/M Technical Center, and prepares the hardware, software, and communication links for the central I/M database. One month before the planned start of operations, the system undergoes a "dry run", inspecting Government and contractor-owned vehicles and recording the results in the database. AirMAC and the Department of Motor Traffic should oversee the contractor's efforts. Meanwhile, AirMAC should launch a public information campaign to prepare the public for the advent of the program, and the Traffic Police should be given training and the mandate to enforce compliance by vehicle owners with the program requirements. (8 months).

The total time remaining before the first phase of the program could be fully operational would be about 21 months.

It is strongly recommended that the Government retain expert technical assistance to aid in preparing the initial bid documents and evaluating the resulting proposals. Following the award of the technical support contract for oversight and supervision, that contractor could take over the technical support function for the authorization of additional inspection centers in subsequent phases.

Once the program goes into effect, AirMac and the Department of Motor Traffic should jointly monitor its operation, with technical support and assistance from the technical support contractor. The I/M standards should be reviewed annually, with a view to gradually tightening them to maintain a reasonable failure rate as the worst-emitting vehicles are repaired, scrapped, or moved outside the critical air quality zone. In this way, it should be possible to achieve substantially lower average emission levels from the existing fleets over a five to seven year period. We suggest that other aspects of the program - geographic coverage, test procedures, vehicle categorization and inspection frequency -- also be reviewed on an annual basis, and that appropriate changes and adjustments be implemented as the vehicle fleet grows in size and in technological sophistication. Ongoing public relations activities should also be undertaken (with funding from the sale of emission certificates) to inform the public of the requirements and the effectiveness of the program, and to educate them as to steps they can take to reduce air pollution as they choose and operate their vehicles. Initially, these programs should focus on increasing public awareness of smoke emissions from diesel and two-stroke vehicles, of their health impacts, and of the need to reduce them. These efforts should seek to apply a social stigma to owning or driving a heavily-smoking vehicle, and should seek to raise awareness of the common causes of high smoke emissions and the feasibility of reducing them.

3.12. CONCLUSIONS

The two most effective measures that could be taken to reduce motor vehicle emissions in Sri Lanka are

1. Establish and enforce appropriately strict emission standards for vehicles newly imported into the country, and
2. Put in place a vehicle inspection and maintenance (I/M) program to identify high-emitting vehicles among those already in the country and require that they be repaired.

Fine particulate matter less than 2.5 microns in aerodynamic diameter (PM2.5) is the air pollutant of greatest concern. PM2.5 exposure increases the risks of respiratory and cardiovascular illnesses, and of premature death. Emissions of smoke and soot from diesel vehicles and from petrol vehicles equipped with two-stroke engines are believed to be among the main sources of PM2.5 emissions in Colombo and other urban areas. Thus, these should be the first and primary targets of the vehicle emission standards and the I/M program.

3.12.1 Vehicle Emission Standards and Import Policy

Establishing and *enforcing* emission standards for newly manufactured vehicles and for vehicles newly imported to the country is the most effective way to reduce vehicle emissions over the long run. Sri Lanka has adopted emission standards for newly imported vehicles, but these standards are not yet effectively enforced.

We recommend the following requirements for vehicles newly manufactured or imported to Sri Lanka (including used vehicles that are imported for the first time):

3. For motorcycles and three-wheelers - certification to Indian rule 115, E.U. Directive 2002/51/EC, or equivalent emission standards;
4. For passenger cars and light commercial vehicles - certification to E.U. Directive 96/69/EC (Euro 2) or equivalent emission standards;
5. For heavy-duty trucks and buses - engines certified to E.U. Directive 1999/96/EC (Euro III) or equivalent emission standards. Engines certified to E.U. Directive 91/542/EEC(b) (Euro II) standards to be acceptable only if equipped with mechanically-controlled fuel injection systems or electronic fuel injection systems demonstrated to be free of control strategies designed to defeat the emission test procedure.

"Equivalent" emission standards include standards established in Japan, the U.S., India, Thailand, etc. that require similar emission control technologies and result in similar or lower emissions per kilometer than the specified E.U. standards.

As long as their quality and emissions performance are adequately checked at the time of importation, continuing to permit used vehicle imports is likely to benefit, and not degrade air

quality. A five-year-old vehicle built and maintained to Japanese or European emission standards is likely to have lower emissions than a brand-new vehicle designed to meet Sri Lankan emission limits. Furthermore, the commercial availability of relatively new used vehicles in good condition will tend to reduce the value and encourage the retirement of the large number of very old vehicles in the present Sri Lankan vehicle fleet.

Two types of vehicles pose especially severe problems for air quality in Sri Lanka: light-duty diesel vehicles and motorcycles and three-wheelers equipped with two-stroke petrol engines. The present preference for diesel rather than petrol engines in light-duty diesel vehicles is an unintended consequence of Government tax and vehicle import policies. These vehicles are very often poorly maintained, and the resulting smoke and particulate emissions are major contributors to illness and premature death from air pollution. Since correcting the tax policies may not be politically and financially feasible, changing vehicle import policies to restrict further imports of light-duty diesel vehicles would be a reasonable "second best" solution.

Two-stroke motorcycles and - especially - three-wheelers are also an important source of PM emissions, and well as grossly excessive emissions of benzene and other unburned hydrocarbons. Motorcycles with four-stroke engines are readily available, and their PM and HC emissions are 80 to 90% less. Although the first cost of four-stroke engines is higher, their better fuel-efficiency results in lower lifecycle costs. We recommend restricting or prohibiting further importation of vehicles - especially three-wheelers - equipped with two-stroke petrol engines.

3.12.2 Vehicle Inspection and Maintenance

A vehicle I/M program is an essential complement to emission standards for new vehicles. Although difficult to implement, an effective I/M program can reduce emissions from uncontrolled vehicles significantly. An I/M program is also needed to ensure that the benefits of new-vehicle control technologies are not lost through poor maintenance and tampering with emission controls. Without an effective I/M programs, compliance with new vehicle emission standards is significantly weakened.

Experience with many unsuccessful and a few successful I/M programs in developing countries leads us to recommend that the vehicle I/M to be implemented in Sri Lanka have the following key features:

- The program should comprise periodic (e.g. annual) inspections, including measurement of emissions, supplemented by on-road enforcement of emission standards with the aid of the Traffic Police.
- Periodic inspections should be carried out *only* in a limited number of high-volume, centralized, test-only inspection stations linked to a central vehicle inspection database. These inspection stations should be established and operated by a small number of private firms (preferably two or three) under government supervision and oversight. They should be equipped with chassis dynamometers (at least for diesel vehicles) and computerized emission analyzer systems to minimize the potential for inspection personnel to affect the test results.

- Compliance with the I/M program requirements should be enforced both through the vehicle registration process (a vehicle that has not passed inspection will not be allowed to re-register) and through the use of counterfeit-resistant window stickers indicating the date by which the next inspection must be passed. It should be illegal to park or operate a motor vehicle without a valid sticker on the public roads in designated "critical air quality areas" such as the Galle - Colombo - Negombo corridor. For reasons of cost-effectiveness, as well as practicality of implementation, the sticker requirement should not apply in rural areas far from urban centers. To avoid the problem of urban vehicles re-registering in such areas, however, the requirement *should* apply to rural vehicles and long-distance transport vehicles while operating in critical air quality areas. To accommodate infrequent visitors, four-stroke petrol vehicles could be allowed to purchase a "visitor pass" - valid for a limited time - *en lieu* of obtaining an inspection sticker
- Government should contract with a suitably qualified company or organization to provide technical support and assist in supervising the I/M program. This organization would maintain master calibration standards, monitor and analyze the inspection results submitted by the inspection stations, organize overt and covert audits of I/M station performance, and provide the analyzers and personnel for on-road emissions enforcement in cooperation with the Traffic Police. It should also review the I/M emissions standards and failure rates on an annual basis, and recommend appropriate tightening of standards as the average level of vehicle emissions goes down. In this way, it should be possible to achieve substantially lower average emission levels over a five to seven year period.
- The capital and operating costs of the I/M program should be recovered through a fee paid by the vehicle owner to the inspection station. The costs of Government supervision and oversight, including the cost of the technical support contractor, should be recovered as part of this fee. We estimate the necessary inspection fees at Rs 1000 for heavy-duty vehicles and Rs 600 for light-duty vehicles, plus a further Rs. 300 to Rs. 500 charge for the emission compliance sticker to pay for enforcement, technical supervision, and oversight.

Given the magnitude of the task, the limited experience with vehicle I/M in Sri Lanka, the limited capacity of the vehicle repair industry, and the shortage of technical resources available, we strongly recommend that the periodic I/M program should not be implemented all at once. Instead, it should be implemented in phases, with priority being given to the vehicles and geographic areas that are of greatest concern (i.e. the Galle-Colombo-Negombo corridor). By confining the initial periodic inspection program to a limited geographic area and only a few classes of vehicles, the difficulties and risks involved in program implementation can be reduced significantly. As the program develops, it can then build on the experience and public acceptance gained with the initial program. A reasonable phase-in schedule for the I/M program would be as follows:

Year 1 - light-duty diesels and three-wheelers

Year 2 - heavy-duty trucks and buses and two-stroke motorcycles

Year 3 - petrol vehicles (including motorcycles) with four-stroke engines

Allowing time for development and issuance of bidding documents, preparation and evaluation of proposals, contract awards, and construction of the inspection stations, the first periodic vehicle inspections could be conducted within about 21 months of the decision to go ahead. To even out the load on the inspection facilities, the inspection times should be staggered, with about one-twelfth of the vehicles required to undergo inspection in any given month.

To implement the proposed I/M program in the Galle-Colombo-Negombo corridor will require about 20 inspection lanes during the first year, divided among 7 to 10 inspection facilities. In the second year, a total of 31 light-duty and 6 heavy-duty inspection lanes would be needed, while the full program would require about 61 light-duty and 6 heavy-duty inspection lanes. The capital investment requirements are estimated at USD 206,000 per heavy-duty I/M lane and USD 120,000 per lane for light-duty vehicles and motorcycles.

A pilot I/M program has been carried out in Colombo. Suitable emission test procedures were developed and applied to characterize the distribution of emission levels among diesel buses, lorries, and light-duty vehicles; among three-wheelers and motorcycles using two-stroke petrol engines; and among motorcars powered by four-stroke petrol engines. The resulting data were used to develop appropriate interim emission standards. If applied, these standards are projected to require emissions-related adjustments and repairs in the first year to approximately 20% of the populations of heavy-duty diesel lorries and buses; 40% of the light-duty diesel population; 41% of three-wheelers; 40% of two-stroke motorcycles; and 44% of light-duty vehicles with petrol engines. Although the failure rates for petrol vehicles may appear high, the great majority of these vehicles can easily be brought into compliance by a simple, quick, and cheap adjustment of the air-fuel ratio, and this adjustment will pay for itself through improved fuel economy. Thus, these limits are considered acceptable and appropriate for the Sri Lankan situation.

For small petrol engines used in three-wheelers and motorcycles, the effect of exhaust pulsations can result in significant dilution of the measured exhaust sample. Two methods of correcting this problem were tested: use of an exhaust pipe extension; and correcting for dilution by means of a mathematical calculation. Neither method was found to be satisfactory by itself, but satisfactory results were achieved by combining the two methods.

The proposed interim emission standards were applied to samples of heavy-duty lorries and buses; light-duty diesel vehicles; and two-stroke three-wheelers and motorcycles. Vehicles found to exceed the standard were required to undergo diagnosis and repairs, or (in the case of two-stroke vehicles) diagnosed and repaired on the spot where possible. Only about one-third of the diesel vehicles and none of the two-stroke petrol vehicles that were cited for exceeding the emission standards actually returned to the RMV for retesting after repairs. This indicates a major problem with the enforcement of existing vehicle technical requirements, which will need to be corrected if the I/M program is to be effective.

The reported data show that almost all of the diesel vehicles that did return to RMV for retesting were able to achieve the emission standards on the first try, at an average repair cost of Rs 12,000 (USD 138). In the case of the two-stroke three-wheelers and motorcycles, the great majority of the failing vehicles were able to be repaired on-site, and at very little cost, to

achieve the emission standards. In most cases, this could be achieved by adjusting the carburetor air-fuel ratio and/or by using the correct fuel and lubricant mixture to reduce smoke emissions.

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Chapter - 4

FUEL QUALITY IMPROVEMENT

4.1. BACKGROUND AND OBJECTIVES

The study on Motor Fuel Quality Improvement in Sri Lanka was conducted within the overall framework of the Urban Air Quality Management Project. The overall objective of the project was to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions. The study was undertaken by the international consultant "Entrast International Limited", UK. The local input for the study has been mainly provided by the Ceylon Petroleum Corporation (CPC).

The main objectives of the Fuel Quality Improvement component of the project are:

- To summarize the international as well as regional trends in fuel quality specifications and the factors driving the specification changes proposed.
- To summarize the arrangement of refineries to meet the tighter fuel specification, particularly in Asia.
- To select fuel quality parameters that would need to be tightened (for example, sulphur in diesel, diesel distillation control, and gasoline RVP) or new limits to be introduced (for example, benzene and total aromatics in gasoline, and manganese as in MMT) covering the period between now and the year 2015 in Sri Lanka, based on the above objectives.
- To suggest reasonable limits based on the likely level of air quality in the future in the major cities of Sri Lanka, based on international experience as well as predicted availability of cleaner fuel in the region
- To analyse the impact of tightened fuel specifications and new limits imposed under two scenarios: (a) no change in the refining sector in Sri Lanka with growing demand to be met by imports; (b) implementation of the proposal to expand the refinery capacity from 50,000 b/d to 100,000 b/d. Also include in the analysis two scenarios for gasoline growth: (a) stagnation of demand for gasoline (because of increasing switch to diesel and LPG); (b) increasing gasoline demand at the expense of diesel demand growth on account of more balanced pricing of gasoline and diesel in the future.
- To estimate the incremental cost of meeting the proposed specifications and propose a feasible timetable, for each scenario given above.

4.2. METHODOLOGIES

In addition to the collection and summarize of the petroleum products supply and demand in Sri Lanka and the quality of transport fuels, the main activities of the study on Fuel Quality Improvement were undertaken under the following main sections:

(i) International trends in fuel quality specifications:
This activity includes a summary of the most important trends in fuel quality world-wide and also revision and discussion on the factors that are driving the fuel specification changes.

(ii) Analysis of current refinery operations and selection of case studies:
The present and future arrangements of refineries to meet the tighter fuel specification are examined, especially in refineries with configurations similar to that of the Sapugaskanda refinery of Sri Lanka. Further the refinery process, facilities and process capacity of Sapugaskanda Refinery are analysed. Considering the combination of these information together with market demand and fuel quality targets, number of case studies are selected.

(iii) Refinery case study:
The case studies are selected in order to separate the effects on costs and product quality of the fundamental variables of the study (i.e. refining capacity, product demand, fuel quality targets, and selection of future, potential, additional refining units). For each case, revenues and costs are calculated taking into account the refinery production, exports and imports.

(iv) Impact of fuel changes on exhaust and evaporative emissions:
The emissions are calculated using an emission inventory model. This model, originally developed for IPIECA (International Petroleum Industry Environmental Conservation Association) by Enstrat International Ltd., has the flexibility to be locally customised and accepts local vehicle populations, vehicle field use data inputs (annual mileage, average traffic speeds, local emission factors when they exist, etc.), typical local fuel qualities.

As regards the emission factors to be used in the model, they were selected to represent Japanese and European vehicles without advanced emission control technologies and without the existence of mandatory Inspection and Maintenance programs. The only exception is the tricycles, for which the model used emission factors adopted for similar vehicles in studies in India and Bangladesh.

For the study and the calculation of the impact on emissions of changing the gasoline and diesel fuel quality, the model is using complex equations that relate variations in individual fuel parameters to emissions. These equations are based on the following research programs:
- Gasoline changes: US AQIRP and European Union EPEFE studies
- Diesel fuel changes: European Union EPEFE study.

Based on the results of the above activities, transport fuel specifications are proposed.

4.3. PETROLEUM PRODUCTS SUPPLY AND DEMAND IN SRI LANKA

The current refining capacity is not sufficient to cover the market demand.

The following tables give a summary of the relative contribution of local production and imports towards satisfying the total market demand, for the period 1990 to 2000:

Table 4.1: Road Transport Fuels -- Demand versus Local Production and Imports, t/y

	Petrol 90 RON at 0,15 g/l lead				Unleaded Petrol 95 RON			
	Demand	Production	Import	Export	Demand	Production	Import	Export
1990)	178,945	179,281	0	0	0	0	0	0
1991)	157,519	137,447	0	0	0	0	0	0
1992)	162,433	112,629	47,781	0	0	0	0	0
1993)	170,443	163,586	0	0	0	0	0	0
1994)	180,690	186,151	0	0	0	0	0	0
1995)	186,064	153,340	10,992	0	0	0	0	0
1996)	194,972	189,314	0	0	0	0	0	0
1997)	191,630	161,002	23,108	0	1,582	0	1,582	0
1998)	201,281	186,749	4,589	247	3,070	0	3,070	0
1999)	213,059	169,339	29,603	0	3,476	0	3,476	0
2000)	224,374	212,330	4,951	0	3,936	0	3,936	0

	Total Diesel (Auto plus Power Gen) (*)			Auto Diesel	Super Diesel			
	Demand	Production	Import	Demand	demand	production	import	export
1990)	511,120	463,012	93,189		16,942	0	16,942	0
1991)	537,975	404,675	170,811		20,132	0	20,132	0
1992)	604,524	298,887	420,129		22,981	0	22,981	0
1993)	664,730	533,490	226,343		23,277	0	23,277	0
1994)	725,733	580,808	196,444		24,484	0	24,484	0
1995)	788,898	556,112	378,343		27,496	0	27,496	0
1996)	1,045,695	584,906	594,173	942,700	28,475	0	28,475	0
1997)	1,294,731	531,989	848,000	955,700	32,515	0	32,515	0
1998)	1,187,138	680,218	585,550	1,115,400	38,470	0	38,470	0
1999)	1,376,772	588,488	880,232	1,227,400	40,048	0	40,048	0
2000)	1,683,523	736,342	1,013,630	1,316,200	46,457	0	46,457	0

(*) From 1998 onwards the total diesel demand includes the distillate used for power generation. Auto diesel figures are shown in the "Auto Diesel - Demand" col

Table 4.2: Road Transport Fuels - Products Imported as % of Demand

	Petrol 90 RON at 0.15 g/l lead	Petrol 95 RON unleaded	Auto Diesel	Super Diesel
	% imported	% imported	% imported	% imported
1990)	0%		18%	100%
1991)	0%		32%	100%
1992)	29%		69%	100%
1993)	0%		34%	100%
1994)	0%		27%	100%
1995)	6%		48%	100%
1996)	0%		57%	100%
1997)	12%	100%	65%	100%
1998)	2%	100%	49%	100%
1999)	14%	100%	64%	100%
2000)	2%	100%	60%	100%

The local refinery is manufacturing enough gasoline to satisfy the bulk of current demand. The relatively small amount of imports are for:

a) satisfying the demand for the 95 RON unleaded grade, and

b) compensating for lower levels of local production in case of refinery maintenance and plant turn-around.

Regarding the diesel fuel, the situation is remarkably different. The Sri Lankan market is clearly biased towards diesel fuel consumption, and the market has more and more evolved in this direction over the last ten years, as shown by the gasoline to diesel consumption ratios of Table 4.3:

Table 4.3: Road Transport Fuels -Trend in Gasoline to Diesel Demand Ratio

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Gasoline to Diesel Demand Ratio	0.35	0.29	0.27	0.26	0.25	0.24	0.21	0.19	0.18	0.17	0.17

This makes the Sri Lankan market practically impossible to satisfy with a single refinery with little conversion capacity. If this trend is not reversed, Sri Lanka will become increasingly dependent on imports, and, in the long range, the viability of the refinery may become questionable.

For these reasons, this study will analyse the impact of tightening fuel specifications under two scenarios:

1) no significant change will take place in the refining sector of Sri Lanka, and all future needs in terms of both demand and fuel quality will be met mostly through imports;
2) the current refining capacity will be doubled, and, at the same time, those investments will be made which are needed to improve the fuel characteristics which would ensure adequate air quality levels in the major Cities of Sri Lanka.

An important prerequisite ahead of the expansion project is an analysis of the present vehicle population and its predicted expansion and composition over the next 10 years at least. This analysis will provide the two following important inputs for the study:
First - a rational basis for predicting future automotive fuel demand,
Second - an assessment of the gap between the current octane fuel quality provided, and that which is actually required by the vehicle population. In the case of gasoline, this study may be particularly important for the special situation in Sri Lanka, where a significant proportion of the total gasoline is used to satisfy the demand of the 3-wheel, 2-T engine vehicles, which have inherently lower octane requirements than the conventional passenger cars.

As regards the other gasoline fuelled vehicles, their fleet octane requirement should be calculated on the basis of vehicle fleet inventory (current and projected over the next 10 years at least) and the manufacturers' recommendations. The octane required by the gasoline vehicle population is likely to be provided more cost-effectively through marketing at least two grades, to satisfy separately the vehicles which require a relatively low octane number (the Japanese imports are satisfied by 90 RON) and those with a higher octane requirement (the European imports have typically a higher octane requirement, around 95 RON).

The demands, productions and imports/exports of fuel products other than gasoline and diesel are reported in the following Tables 4.4a, 4.4b, and 4.4c:

Table 4.4.a: Furnace Oil and Kerosene - Demand versus Local Production and Imports, t/y

	HFO (Furnace oil)				Kerosene			
	Demand	Production	Import	Export	Demand	Production	Import	Export
1990)	157,774	582,737	0	98,306	167,241	171,097	0	0
1991)	199,741	570,652	0	104,874	173,931	151,363	5,117	0
1992)	254,942	458,055	70,685	5,706	189,373	127,149	0	0
1993)	220,828	563,551	0	67,396	191,795	188,950	0	0
1994)	232,137	602,502	0	91,091	207,991	192,006	0	0
1995)	241,140	582,021	30,650	95,513	222,341	192,339	0	0
1996)	341,464	748,955	0	78,514	228,389	200,649	0	0
1997)	371,581	663,966	0	79,726	225,195	146,962	9,836	0
1998)	556,048	715,639	0	19,918	235,909	203,933	15,377	0
1999)	557,558	631,397	58,664	21,127	243,368	167,263	15,659	0
2000)	736,705	742,289	62,011	0	227,789	191,965	10,151	0

Table 4.4.b: LPG and Jet Kerosene - Demand versus Local Production and Imports, t/y

	LPG				Jet Kerosene (Avtur)			
	Demand	Production	Import	Export	Demand	Production	Import	Export
1990)	34,900	18,692	16,208	0	118,339	100,589	31,355	0
1991)	37,800	18,888	18,912	0	111,830	90,207	39,834	0
1992)	44,700	14,344	30,356	0	131,182	69,114	123,437	0
1993)	52,800	16,614	36,186	0	138,227	90,522	67,551	0
1994)	63,600	15,266	48,334	0	146,774	60,960	98,384	0
1995)	78,000	13,705	64,295	0	168,334	67,311	142,647	0
1996)	87,000	18,428	68,572	0	195,282	68,584	166,916	0
1997)	100,000	13,894	86,106	0	204,607	73,747	202,613	0
1998)	117,000	18,172	98,828	0	199,950	53,909	167,275	0
1999)	139,000	13,103	125,897	0	240,700	53,927	252,120	0
2000)	140,000	16,817	123,183	0	259,452	92,159	214,848	0

Table 4.4.c: Naphtha - Demand versus Local Production and Exports, t/y
(*) Excess naphtha not used for gasoline blending

	Naphtha			
	Demand	Production (*)	Import	Export
1990)	0	73,291	0	75,553
1991)	0	85,339	0	88,069
1992)	124	72,635	0	76,879
1993)	0	118,489	0	119,617
1994)	0	113,659	0	113,191
1995)	0	119,645	0	110,025
1996)	0	103,553	0	112,102
1997)	0	98,776	0	93,296
1998)	0	119,137	0	139,376
1999)	0	99,468	0	84,595
2000)	0	112,613	0	109,616

The following should be noted:

- The production of Furnace Oil and normal Kerosene was, up to now, adequate to satisfy the local market
- The market demand for LPG is significantly higher than local production
- On average, between 50 and 90 % of the Jet Kerosene demand is satisfied by imported fuel
- Only about 50% of the total naphtha produced is used for blending gasolines. The remaining is exported. This gives scope for increasing the gasoline production by:
  a) either building a naphtha isomerization unit that increases the RON of this product from less than 70 to a level of about 83; or
  b) importing high octane gasoline blending components (such as MTBE) which allow to use the relatively low RON naphtha in gasoline blends.

In this situation, in order to better balance fuels production and demand, the following course of actions seems to be appropriate for Sri Lanka:

- Take fiscal measures which tend to increase the gasoline demand at the expense of the growing diesel fuel demand.
- Expand the refinery capacity to continue to satisfy local demands for gasoline, normal kerosene and reduce imports of LPG and Jet Kerosene
- Invest in a hydro-cracker plant to increase production of gasoil and hence reduce imports of diesel fuel
- Invest in a naphtha isomerization plant, to upgrade the naphtha to gasoline blending component.

These measures would give the local refinery the flexibility to meet more advanced fuel quality specifications, in line with current and future environmental requirements. A combination of these measures (with and without the plan for a refinery expansion) will be the subject of this study.

4.4. THE QUALITY OF TRANSPORT FUELS

The fuel quality parameters that should be considered in controlling vehicle emissions and air quality will be discussed in the first chapter of this report and include:

- for gasoline: lead, benzene, total aromatics, front-end-volatility (RVP), sulphur.
- for diesel fuels: sulphur content, T95, Cetane Number/Index, density, poly-aromatics.

The refinery crude slate, the refinery configuration, the operation severity of the key refinery processes, and the relative demands of the various products are all essential features that influence product quality. Therefore the optimisation of these parameters will form the subject of this study.

4.4.1 Current Gasoline and Diesel Fuel Specifications and Quality

Tables 4.5 and 4.6 list the current Sri Lankan specifications for gasoline and diesel fuel respectively:

Table 4.5: Current Gasoline Specifications

Properties	90 RON Leaded	95 RON Unleaded
RON, min	90	95
Lead,g/l max	0.30	0.013
RVP, kPa max	62.1	70
Benzene, %vol. Max	8.0	8.0
Sulphur, ppm max	1000	1000
10% point, deg.C	45/70	45/70
50% point, deg.C	80/125	80/125
90% point, deg.C max	180	180
FBP, deg.C max	205	215
Res. %vol. Max	2.0	2.0
Oxygenates, %vol.max		15
(RON+MON)/2, min		89

Table 4.6: Current Diesel Fuel Specifications

Properties	Auto Diesel
Sulphur, ppm max	10,000
Cetane Index, min or	45
Cetane Number, min	48
Density, kg/m3 max	870
T90, deg C max	370
Aromatics, %	not specified
Viscosity, kin.@37.8, cst	1.5/5.0
Flash point(PMCC), C max	60

These specifications are likely to be enforced until late 2002. New specifications will be introduced on the 1st of January 2003, as required by the extraordinary issue of the 23rd of June 2000 of The Gazette of the Democratic Socialist Republic of Sri Lanka (No. 1,137/35).

These new specifications are part of a package of measures (The Motor Traffic Act) aiming at the reduction of traffic emissions, and are:

Table 4.7: 2003 Gasoline Specifications (Emission related standards)

Properties	Unleaded Gasolines
RVP, kPa max	60
Total Aromatics, max	45
Benzene, %vol. max	4
Lead,g/l max	0.013
Sulphur, ppm max	1000
Gum (solvent washed),max	40
RON, min	87/95
Oxygenates, %vol.max (MTBE,ETBE,Alcohol)	15
Oxygen, %m/m max	2.7

Table 4.8: 2003 Diesel Fuel Specifications (Emission related standards)

Properties	Auto Diesel
Cetane Index, min or	46
Cetane Number, min	48
Density, kg/m3 max	860
T90, deg C max	370
Sulphur, ppm max	5000

The 2003 specifications will certainly be one of the targets of the present study. The analysis of the international and regional fuel quality trends (Section 4.5) is likely to add additional fuel quality targets, particularly for the period 2005 to 2015. It is worth noting that, regarding the diesel fuel back-end volatility, the specifications of Table 4.8 limit the T90, while in the rest of the study the targets are defined in terms of T95, since recent research work has established that it correlates better with the emission of particulate matter. Regarding the RON specification, a limit of 87 min is not sufficient to satisfy the octane needs of the gasoline vehicles of Sri Lanka, and to keep them free from engine knocking with consequent high emissions, higher fuel consumption and possible engine damage.

4.4.2 Typical Quality of Products versus Specifications

Considering the current structure of the Sri Lankan refinery (topping /reforming with some visbreaking capacity), and the consequent quality of the component streams available for blending the finished gasoline and diesel fuel, it is possible to have a clear impression of the refinery challenges in meeting the above specifications:

Gasoline:

a). all naphtha is hydro-treated before being split into blending naphtha and reformer feed. This ensures that the sulphur content of the final gasoline blend is very low, typically below 5 ppm.

b). the cut point in the naphtha splitter is quite high (around 95 to 100 deg.C). This ensures that the benzene precursors are not included in the reformer feed. This approach produces a reformate with low benzene content, and gives typical benzene values of the finished gasoline in the range of 3.0 to 4.0 %.

c). the only high octane number blending component available in the Sri Lankan refinery is the reformate, which is used in high proportions in the final gasoline blends. This has two effects: a) the aromatic content tends to be above 40%, b) the RVP of the gasoline

blend tends to be low (around 50/55 kPa) as the RVP of the reformate is low (typically below 40).

d). the Solvent Wash Gum limit should be easily and consistently met, as the refinery has no catalytic cracking unit, and therefore all blending streams have very low olefins contents.

e). RON: a value of 90 minimum is necessary to satisfy the octane requirement of the Japanese imported car population (a special grade with a minimum of 95 RON is needed to satisfy the European imported cars).

The currently available gasoline blending components are not likely to be adequate to blend quantities of 90 RON unleaded gasoline that are enough to satisfy the market demand. Purchase of high octane components or investments in new refinery process units is likely to be necessary, as it will be discussed later in the study.

Diesel Fuel:

a). the diesel fuel is blended with a very large proportion of straight-run gasoil and with a small amount of visbreaker gasoil. The available gasoil hydro-treating capacity is low and not enough to hydro-treat the entire diesel fuel production of the refinery. The product quality implications of this situation are listed below.

b). the cetane index and number limits should be consistently met.

c). both the density and T95 values are likely to be close to the upper limits of the standards.

d). the Sulphur limit for 2003 will not be met unless some of the following actions are implemented:

- import low sulphur gasoil to be blended with that locally produced
- expand the gasoil hydro-treating capacity of the refinery
- move to a crude slate which includes a significantly higher proportion of low sulphur crude. (the latter measure may not be sufficient on its own, and it may have to be implemented in combination with either one of the other of the two above).

This preliminary analysis of the current and 2003 specifications, vis-à-vis the current refinery structure, can begin to give some clues about the directions of this study.

4.5. INTERNATIONAL TRENDS IN FUEL QUALITY SPECIFICATIONS

4.5.1 Introduction

This chapter provides a summary of the most important trends in fuel quality world-wide. The factors that are driving the fuel specification changes are also reviewed and discussed. As a next step, the report examines how the various refineries have either coped with the specification changes or are planning to meet them in future. In this latter analysis, the report will concentrate especially on topping-reforming refineries, i.e. on refineries with configurations similar to that of the Sapugaskanda refinery of Sri Lanka.

4.5.2 General Considerations on Moving to Unleaded Gasolines

In the last 25 years leaded gasolines have been substantially reduced, or eliminated altogether, in a growing number of countries. Two very important considerations can be made based on this 25 years experience:

first: no vehicle operational problems of any significance have been observed, not even in the area of exhaust valve-seat recession, which was a concern for old cars before the gasoline unleaded grades were introduced in the market. The case of Brazil is especially significant, given the size and the vehicle age profile of the Brazilian car fleet. With the use of up to 22% of ethanol in gasoline blends, the lead additives were no longer needed to meet the required octane quality, and gasoline lead was gradually phased-out from 1979 onwards and totally eliminated from 1991.

second: as the elimination of lead from gasoline has implications which go far beyond the simple removal of lead from the fuel, an integrated strategy for air pollution abatement - associated to a fuel reformulation programme - has been integral part of all successful plans for lead phase-out. In fact, as lead is an octane booster, lead removal lowers the octane of the unleaded gasoline pool, and this octane shortfall must be compensated by other components. However, there are environmental consequences for most changes made in gasoline composition. One typical example is the use of more reformate to compensate for the elimination of lead; this step increases significantly the aromatic content of the gasoline, including the concentration of benzene, that is a known carcinogen. However, as it will be discussed later, it is possible to eliminate lead without necessarily increasing the benzene content of the fuel, albeit with some additional investments.

4.5.3 Worldwide Fuel Re-formulations: What Are They And What Is Driving Them

In examining the fuel reformulation programmes that were implemented over the last 25 years, we can divide them into two major categories:

a). those fuel specification changes which have been made because of the direct beneficial impact of the change on either exhaust or evaporative emissions of the vehicle fleets. These changes were usually made in steps over a number of years, in most cases in at least two steps.

b). more recently however several very advanced specification changes have been made or are being planned so that future fuels can enable the market introduction of very advanced engine emission control technologies.

The following table lists the major specification changes that have occurred or are being planned under a) and b). For sake of simplification, the a) type changes have been grouped in two steps.

Table 4.9: Emission Control -- Specification Evolution

		Direct Impact on Emissions		Enabling Specifications
		First step	Second step	Third step
Gasoline	Lead, mg/l	13		5
	Benzene,%	2.5	0.7 to 1.0	
	RVP,kPa	60-75(*)		
	Aromatics,%	40	35	
	Oxygen,%	1.0 to 1.5	up to 2.7	
	Sulphur,ppm	250	150	30
Diesel fuel	Sulphur,ppm	2000 to 1000	500 to 300	50 to 10
	Cetane N.	49	50	52
	Density	850	840	
	Poly-Arom.,%	12	5.0 to 1.0	
	T95, deg.C	370	350	

(*) Depending on climatic conditions

In most cases, two grades of unleaded gasoline meeting the above specifications were introduced in the market. One grade with an RON in the range of 92 to 95, and the other grade usually with a lower RON (85 to 92) depending on the local needs and the octane requirements of the local car populations. More rarely, a higher octane grade around 98 RON was also introduced, but with very small market demands. In general the rationale for the specification changes of the above table was the following:

1). Gasoline - Lead:

Historically, the first step in gasoline reformulation has been the removal of lead. This happened for two reasons: lead is extremely toxic and is emitted as exhaust particulate matter. Furthermore it is an obstacle to the use of catalytic converters, as it permanently

deactivates them. From this point of view, it must be noted that even the small allowed contamination of up to 13 mg/l is not tolerated for the most advanced catalytic systems currently being introduced in the North American and western European markets. For these new catalyst technologies, which reduce emissions of CO, HC, NOx by more than 95%, a much smaller lead contamination is allowed.

2). Gasoline - Benzene:

The carcinogenicity of benzene has been the reason for the high level of attention this component has received and for the world-wide attempts to reduce its emissions. Reducing the amount of benzene in gasolines is a good first step in tackling at least 80/90 % of the total benzene emissions by transport sources. However a much smaller, but still significant, part of the benzene in gasoline vehicle exhaust is also formed during the combustion process from other aromatics present in the gasoline blends (as an example, on average, 10% to 15% of other aromatic components give the same contribution to benzene exhaust emissions of 1% benzene in the gasoline blend). The addition of oxygenates to the blend reduces the amount of benzene emissions through three different separate approaches:

a). by simple direct dilution of the aromatic streams

b). by providing a more intimate contact between hydrocarbons and oxygen during the combustion process, which reduces the emissions of both unburnt hydrocarbons (including benzene) and CO.

c). by providing high octane blending components which allow to back-off some reformate from the blend and hence reduce the total aromatics and the benzene contents of the fuel.

3). Gasoline – RVP (Reid Vapour Pressure):

The Reid Vapour Pressure describes the tendency of the fuel to evaporate and hence to emit hydrocarbon vapours into the atmosphere. Reducing RVP is probably the most cost-effective way of controlling hydrocarbon emissions, as it substantially reduces the evaporative emissions from the gasoline distribution system, the vehicle refuelling operation, and the evaporative emissions from the vehicles themselves. RVP limits have therefore proved effective in controlling the occurrence of ozone pollution episodes.

4). Gasoline - Aromatics:

On top of contributing to the reduction of benzene emissions, lower aromatics provide two additional benefits:

a). directionally lower emissions of total hydrocarbons from engine exhausts

b). reduction of emissions of heavy HC, including Poly-Nuclear Aromatic compounds (some of which are known carcinogens)

5). Gasoline - Oxygenate components:

Oxygenate components (like MTBE) were first blended into gasolines as octane boosters for unleaded grades. However, at a later stage they were used to reduce exhaust emissions of Carbon Monoxide (CO) and, to a lesser extent, of unburnt hydrocarbons. The beneficial impact of the use of oxygenates on benzene emissions is discussed under the benzene heading.

6). Gasoline – Sulphur:

Sulphur compounds enter gasoline blends mainly through cracked components. These processes are widely used in modern and more complex refineries for converting heavy refinery streams into lighter more valuable products. Therefore, in a topping-reforming

refinery the sulphur content of the gasoline blends is fairly low. Sulphur in gasoline has a significant impact on emissions of catalyst equipped vehicles, as it can reduce quite drastically the efficiency of the catalyst, particularly before the catalysts reaches its optimal operating temperature. For vehicles not equipped with catalytic converters, sulphur has no effect on emission levels, except that of SO_2, which can give a small contribution to the total particulate matters emitted by transport sources. Very low levels of sulphur (below 30 ppm) are recommended by equipment manufacturers as enabling fuels that do not contribute to the deterioration of the latest catalyst technologies suitable for LEV (Low Emissions Vehicles) and ULEV (Ultra Low Emissions Vehicles) type vehicles.

Diesel Fuel:
Measures that are being considered in diesel reformulation include, in order of priority, sulphur reduction, distillation curve control (particularly the back-end part of the distillation curve), cetane number/index enhancement, density control and aromatics (particularly poly-aromatics) reduction.

7). Diesel Fuel - Sulphur Content:
The emission benefits of low sulphur diesel fuels are reduced SO_2 and PM10 emissions. Because of this, the diesel fuel sulphur content has been gradually reduced over the last 30 years from 8,000/10,000 ppm (or 0.8 to 1.0 %) to levels around 500 ppm or slightly below. These levels have already been achieved in some countries, while other countries have adopted them as targets to be met in future. The very low levels (below 50 ppm) of Step Three of Table 4.9 are a requirement of equipment manufacturers to enable the use of the following two future diesel engine technologies:
a) de-NOx catalysts for NOx reduction
b) self-regenerating traps for Particulate Matter (PM)

These two technologies are still at the pre-commercial level, but are likely to be required for meeting the NOx and PM_{10} limits for diesel engines already legislated in Western Europe for 2005 and 2008. A diesel sulphur limit of 50 ppm max is part of the European legislation for 2005.

8). Diesel Fuel - Cetane Number:
Cetane Numbers are increased in order to reduce emissions mainly of NOx and, to a lesser extent, of PM10. In fact there are studies in which an increase of the Cetane Number did not cause any statistically significant reduction of particulate matter. Reducing NOx emissions is particularly important in areas that are subject to severe ozone occurrence episodes. Cetane number specifications tend to be a severe challenge for cat-cracking refineries, as the cycle oils have very low Cetane qualities. Topping-reforming refineries tend to produce diesel fuels with good cetane quality, as the straight-run gasoils have good Cetane number values.

9). Diesel Fuel – Density:
Lowering density enables the fuel/air mixture of the diesel engine to become even leaner, as diesel engines inject a constant volume of fuel into a fixed amount of air. Lower densities, and hence leaner mixtures, tend to reduce PM10, hydrocarbons and carbon monoxide emissions.

10). Diesel Fuel- Poly-Aromatics:
Aromatics in general, and poly-cyclic aromatics in particular, increase PM10 emissions,

particularly from heavy duty direct injection engines. Poly-aromatic hydrocarbons are mainly a severe problem in diesel fuels blended with products manufactured in catalytic cracking units, which convert heavy refinery streams into naphtha and gasoil blending components.

11). Diesel Fuel - T90 or T95:

The heavier end of the diesel fuel contributes to PM10 emissions. For this reason, essentially all diesel fuel reformulation programmes include limits on either T90 (i.e. the temperature at which 90% of the fuel is distilled) or T95. Many refineries, particularly in warm climates, tend to produce diesel fuels with high T90/ T95, with the aim of maximising the diesel yields. This makes the problem of PM10 emissions directionally more severe.

In general, studies carried out both in the USA and Europe indicated that the diesel fuel parameters, which are most effective in controlling the emissions of PM10 and NO_x (the two critical pollutants emitted by diesel engines), are:

a). PM10: decreasing sulphur, poly-aromatics, density and T90/T95 in indirect injection light duty engines; decreasing sulphur, poly-aromatics in direct injection heavy duty engines;

b). NOx: decreasing poly-aromatics in indirect injection light duty engines; decreasing poly-aromatics, density and T90/T95, and increasing cetane in direct injection heavy duty engines.

These complex and comprehensive studies provided the scientific foundation on which the most advanced diesel fuel specifications of the USA and Western Europe are based. Countries that have not yet introduced any diesel reformulation, with the specific intent of reducing emissions from diesel engines, should, as a first step, control the sulphur content and T90 or T95, for the following reasons:

a). in these countries, T90 and sulphur levels tend to be high. In fact while the USA and Europe have reduced the sulphur level to the 500/350 ppm range, many developing economies still have legally permissible sulphur limits in the range between 10,000 and 5,000 ppm. Furthermore, their T90 or T95 can also be several tens of degrees Celsius above the current USA and European limits. Therefore, controlling these two parameters shall lead to a significant reduction of PM10 emissions, with obvious human health benefits.

b). the reduction of T90/T95 tends to reduce the amount of heavy aromatics in the fuel

c). the T90/T95 limit would also reduce the NOx emissions from the buses and goods distribution trucks that have usually a big impact on urban air quality.

However, depending on the crudes processed, sulphur and T90/T95 reductions could require significant refinery investments and entail additional product costs, as it will be seen in the next chapters.

As a general consideration at the end of this section of the report, it is important to note that, for countries that have forged ahead with severe and expensive fuel reformulation programmes, one of the drivers was tackling the ozone problem, which is not yet an issue in Sri Lanka. This is particularly true for fuel reformulation programmes which aimed at substantial reductions of hydrocarbons and nitrogen oxides emissions.

4.5.4 Actual Specifications Adopted Worldwide - Gasoline

4.5.4.1 Reformulated Gasolines in the USA

The USA has a long history of gasoline reformulation both at the Federal level and the local States' level, beginning with the introduction of unleaded in the early 1970s. Currently in the USA a complex model is used which relates fuel quality to vehicle emissions. Table 4.10 gives typical values for the key gasoline compositional parameters.

Table 4.10: Typical Values of US Federal & Californian RFGs

	US Federal Reg. Grade	US Federal Mid.Grade	US Federal Pm Grade	CA Phase II Reg. Grade	CA Phase II Mid.Grade	CA Phase II Pm Grade
RON, typ. Min	92	94 to 96	98	92	94 to 96	98
MON, typ. Min	83	85	87	83	85	87
Benzene,vol.% max	0.95 (avg.)	0.95 (avg.)	0.95 (avg.)	1.2(*)	1.2(*)	1.2(*)
Aromatics, vol.% max	27 (approx.)	27 (approx.)	27 (approx.)	25	25	25
Oxygen, wt %	2.1 (avg.)	2.1 (avg.)	2.1 (avg.)	1.8 to 2.2	1.8 to 2.2	1.8 to 2.2
Olefins, vol.% max				6	6	6
Sulphur, wt ppm,max	180 (approx.)	180 (approx.)	180 (approx.)	40	40	40
T90, deg.C max	185 (approx.)	185 (approx.)	185 (approx.)	150	150	150
RVP, kPa max	49 to 55	49 to 55	49 to 55	48	48	48

(*) 1.2% is the absolute limit, which should never be exceeded at the pump. The rolling average value, over a period of 3 months, should not exceed 0.6%

The regular and mid. grades represent the vast majority of usage. Therefore the octane level of the gasoline pool tends to be around 93-95 RON and about 84 MON.

As regards the other specifications, the following is worth noting:

a). benzene and aromatics contents are kept low to reduce emissions of benzene and other toxics

b). the sulphur level (particularly in California) is kept very low, to ensure good catalyst operability

c) the RVP levels are very low, as RVP is recognised as the most effective (and also cost-effective) measure to reduce total emissions of hydrocarbons by reducing evaporative emissions.

Because of the emphasis on maximising gasoline production, the vast majority of US refineries are based on high cat-cracking capacities. The RFGs requirements have been met with additional investments in alkylation and isomerization units and with the use of substantial amounts of oxygenates in the blends. Products from alkylation and isomerization plants allow to increase the octane number of the finished gasoline blend without increasing its content of total aromatics and benzene.

The US experience has very little relevance to the situation of the Sri Lankan refinery. In fact, because of the large distillate demand in Sri Lanka, it is not advisable to invest in a cat-cracker, and in the absence of a cat-cracker there are no suitable feed-stocks for an alkylation plant. However, the other two measures of investing in an isomerization unit and using oxygenated blend stocks are relevant to Sri Lanka, as it will be discussed several times in this report.

4.5.4.2 Reformulated Gasolines in the European Union

Also in Europe, the first approach to fuel reformulation consisted in step wide reductions of the lead content, leading to a complete lead elimination in 2000. As regards the evolution of the other gasoline characteristics, they are summarised in the following Table 4.11.

Table 4.11: Current and Future European Union Gasoline Specifications

	EURO II 1996	EURO III 2000	EURO IV 2005	EURO V 2008/9
RON, typ. Min	95 (*)	95 (*)	95 (*)	95 (*)
MON, typ. Min	85	85	85	85
Benzene,vol.% max	1.0	1.0	1.0	1.0
Aromatics, vol.% max	N/A	42	35	35
Oxygen, wt %	N/A	2.7max.	2.7max.	2.7max.
Olefins, vol.% max	N/A	18	18	18
Sulphur, wt ppm,max	500	150	50	10
E150C, vol.%	N/A	75	75	75
RVP, kPa max	70	60	60	60

(*) A 98 RON grade meeting the same specifications is also marketed (about 5% of demand)

Comments:

a). the benzene and aromatics contents are reduced to low levels to reduce the emissions of toxic carcinogens.

b). a minimum oxygen content is not mandated, as oxygenates are mainly reducing CO emissions and CO is not an air quality issue in the European Cities. However oxygenated compounds equivalent to 2.7% max. of oxygen can be used as blending components, usually as octane boosters. The limit of 2.7% max has been set for vehicle operability reasons.

c). low RVP values are imposed as a cost-effective measure to reduce total hydrocarbon emissions.

d). the sulphur content is low and becoming even lower in 2005 to ensure good catalyst performance.

Of the about 100 refineries still in operation in the European Union, at least 20 are of the topping-reforming type. Therefore their experience in meeting the above specifications is relevant to the situation in Sri Lanka. These simple refineries rely on catalytic reforming of naphtha as their major source of octane and had to undergo severe changes in their gasoline blending practices to meet the quite tight benzene and aromatic specifications. The totality of these refineries took the following steps:

First: maximisation of the use of MTBE (sometimes TAME) either purchased or manufactured in the refinery itself.
Second: purchase of low-aromatics high-octane blending components, such as alkylates
Third: invest in isomerization units to process all available C5/C6 molecules and/or naphtha from crude distillation. In a few cases more sophisticated processes were used (mainly to meet the 1% benzene specification), involving:
- reformate splitting to segregate a light benzene-rich fraction.
- hydrogenation of the light reformate to saturate the benzene to cyclohexane.
- isomerization of the hydro-saturated light reformate (to restore an adequate octane blending value for this stream, as the RON of cyclo-hexane is about 18 points lower than that of benzene)

4.5.4.3 Tightened Gasoline Specifications in Australia/Japan/Korea

All three countries have moved to unleaded gasolines. Table 4.12 shows the main specifications either already implemented or planned between now and 2005.

Table 4.12: Current and Future Gasoline Specifications in Australia/Japan/Korea

	Australia 1999	Australia 2003	Japan 2000	Japan 2005	Korea 2000	Korea 2004
RON, typ. Min	91 to 93	95	91Reg/98Pm	91Reg/98Pm	91Reg/98Pm	91Reg/98Pm
MON, typ. Min	N/A	N/A	82Reg/87Pm	82Reg/87Pm	82Reg/87Pm	82Reg/87Pm
Benzene,vol.% max	N/A	N/A	1.0	1.0	2.0	1.0
Aromatics, vol.% max	N/A	42	40	40	35	25
Oxygen, wt %	N/A	N/A	N/A	N/A	1.3 to 2.3	1.3 to 2.3
Olefins, vol.% max	N/A	18	25	20	23	10
Sulphur, wt ppm,max	500	150	100	30 to 50	200	40
T90, deg.C max	N/A	N/A	180	180	175	160
RVP, kPa max	N/A	70	72	56 to 60	59	59

Comments:

a) Australia has the simplest set of specifications discussed so far in this report. However the sulphur spec. is low enough to ensure good catalyst operability.
b) contrary to the Octane strategies in USA, EU and Australia (main grade at 95 RON), Japan and Korea market two grades at 91 and 98 RON respectively, with 91 RON being the main grade.
c) Japan and Korea follow the USA and the EU regarding benzene and aromatics specifications
d) Only Korea makes extensive use of oxygenates, most likely due to the very low aromatics limit
e) by 2005, both Japan and Korea plan to reduce the sulphur level to the same range of the EU and California (40-50 ppm) to ensure compliance with the predicted needs of LEVs and ULEVs (very low emission vehicles).
f) Also Japan and Korea recognise the value of low RVP specifications to control hydrocarbon emissions.

Similarly to the USA, both Japanese and Korean refineries are mostly geared towards gasoline productions, rather than distillate production. Therefore, regarding the relevance to Sri Lanka of the measures taken in these two countries, the comments made in section 4.5.4.1 (US RFG) apply.

4.5.4.4 Proposed Guideline Gasoline Specifications in Latin America and the Caribbean

A common set of key technical specifications for transport fuels has been proposed for application throughout Latin America and the Caribbean. Although it is the prerogative of individual countries to set national standards at levels they consider appropriate, these proposed specifications are intended as minimum standards throughout the region. These proposed guideline specifications are listed in Table 4.13.

Table 4.13: Proposed Guideline Gasoline Specifications for Latin America and the Caribbean (issued in1998)

Specification	Value 2001	Value 2005
RON,min	91 & 95	91 & 95
MON,min	82 & 85	82 & 85
RVP,psi,max	9.0 to 11.5 (*)	9.0 to 11.5 (*)
T50, deg.C, max	120	120
T90, deg.C, max	190	190
Sulphur, wt ppm	1,000	400
Aromatics, vol % max	45	45
Olefins, vol % max	25	25
Benzene, vol % max	2.5	2.5
Oxygen, wt % max	2.7	2.7
Lead, g/l max	0.013	0.013

(*) depending on climatic conditions

These guidelines specifications are less severe than those reviewed so far for USA, EU, Australia, Japan and Korea. However they represent a good starting point, as minimum standards, for the developing economies of Latin America and the Caribbean. In particular, the following is worth noting:

a). of the two gasoline grades, the 91 RON tends to be the higher volume grade in most countries.

b). by 2005, the sulphur content will be lowered to ensure good catalyst efficiency.

c). the benzene content is reduced to 2.5% max, which is a good step in the right direction, particularly for topping-reforming refineries.

d). some countries, like Chile are introducing more severe specifications, mainly for sulphur, as they are importing cars with catalytic converters.

In the Latin American and Caribbean countries there is a range of refineries from simple topping-reforming to more complex cat-cracking ones. Planning studies have identified the investments needed for each refinery type to comply with the above specifications while moving to unleaded:

Topping-reforming refineries
Reformer expansion *Isomerization* Use of MTBE

Cat-cracking refineries
Reformer expansion Isomerization Use of MTBE Alkylation

This is consistent with the approach followed by topping-reforming refineries world-wide.

4.5.4.5 Proposed Guideline Gasoline Specifications for Countries in Central Asia and the Caucasus

The UNDP and the World Bank (Energy Sector Management Assistance Programme) have jointly sponsored a study on "Cleaner Transport Fuels for Urban Air Quality Improvement in Central Asia and the Caucasus". As part of this study, a set of gasoline specification was proposed for this Region, as shown in Table 4.14.

Table 4.14: Proposed Guideline Gasoline Specifications for Countries In Central Asia and the Caucasus (issued in 2001)
(The timing and compositional limits of this table should be assessed in a few years)

Fuel Parameters	Grade A 2005	Grade A 2015	Grade B 2005	Grade B 2015
RON, min	91, 93, 95	91, 93, 95		
MON, min			76/80	76/80
Lead, g/l max	0.013	<<0.013	0.013	<<0.013
Benzene, vol.% max	5.0	2.0 (or 1.0)	5.0	2.0 (or 1.0)
Aromatics, vol.% max	no limit	45	no limit	35
Sulphur, wt. Ppm	no limit	300	no limit	300

Each of the various countries in the region market at least two gasoline grades: one with a MON in the 76-80 range, aimed at old low compression ratio gasoline vehicles, and one with an RON between 91 and 95 for the other more modern vehicles.

All grades should be unleaded from 2005, with a benzene limit of 5% max. By 2015, it is proposed to reduce the benzene content to 2% (or even 1%) and also to limit the total aromatics content to 45% for the 91-95 RON grades and to 35% for the 76-80 MON grades

By the same year 2015, also the sulphur content will be reduced - to a level of 300 ppm max - to prepare the market for the introduction of cars with more sophisticated emission control technologies, such as the catalysts.

The refinery facilities in the study area range from very simple to complex conversion ones. However, out of a total of 11 refineries considered in the study, 5 were topping-reforming, with or without some simple conversion units like visbreaking or coking.

For the topping-reforming refineries which have similarities with Sapugaskanda, the following was recommended in order to move to unleaded gasolines while meeting the above stricter specifications for benzene, aromatics and sulphur:

	Refinery A	Refinery B	Refinery C	Refinery D	Refinery E
Isomerization unit	yes	yes	yes	yes	Yes
Use Ethanol in blends	yes	yes			
Increment Reformer Capacity		yes			

Comments:

a). because of local economics, the use of Ethanol as a high octane component was recommended instead of MTBE (from a technical point of view, there is little difference between the two products).

b). an isomerization unit was recommended for all plants.

c). only one plant necessitated more reformer capacity.

4.5.4.6 Recent Gasoline Specifications in South East Asian (S.E.A.) Countries

Most SEA countries have been very active, over the last 5 to 10 years, in tightening their national gasoline specifications, with the aim of reducing emissions from transport sources. The current situation for Singapore, Malaysia, Thailand and the Philippines is as follows:

Table 4.15: Recent Gasoline Specifications in South East Asian (SEA) Countries (Source: National presentations at ADB regional workshop, New Delhi, May 2001)

	Singapore 2000	Malaysia 2000	Thailand 2000	Philippines 2001	Philippines 2003
RON, typ. min	92-97	various grades	87-91-95	81-93-95	81-93-95
MON, typ. min	85	various grades	84		
Benzene,vol.% max	3.0	5.0	3.5	2.0	2.0
Aromatics, vol.% max	50		35	45	35
MTBE, vol.% max	15	10	5.5 to 11.0	10	10
Olefins, vol.% max			15		
Sulphur, wt ppm,max	500	1500	1000	2000	1000
T90, deg.C max	180		170		
E150C, vol.% min				70	70
RVP, kPa max	70	70	60	62	62

Comments:

Philippines: Lead phase-out in Metro-Manila from Jan. 2000, and nation-wide from Jan. 2001. RVP limits were introduced in 2001; further stringent limits for benzene and aromatics will be introduced in 2003. Initiatives to favour CNG and LPG as automotive fuels

Thailand: First unleaded gasoline grade - 95 RON - introduced in the market in 1991. The phase out of leaded gasolines has been completed in 1995.
Singapore: Lead has been completely phased out.
Malaysia: At least 90% of the total gasoline sold is unleaded, but a small amount of leaded at 0.15 g/l lead max. is still being marketed.

The refineries in this region, and particularly in Singapore, Malaysia and Thailand, are quite complex and have a sizeable level of conversion capacity. Therefore they have the capability of blending the unleaded gasoline grades from a fairly broad range of refinery streams, coming from reformer splitting units, alkylation and isomerization plants of various types and severity. On top of that, they are all using significant amounts of MTBE as blending components.

Some limited data is available from other South East Asian countries, mainly regarding the octane level and the sulphur and lead contents, as shown in the following additional Table 4.16.

Table 4.16: Gasoline Specifications in Other S.E.A. Countries (Source: ADB Workshop, New Delhi, May 2001)

	Brunei 2000	Indonesia 2000	Myanmar 2000	Vietnam 2000
RON, typ. min		88-94-95	92	
Lead, g/l max	0.11	0.005-0.30		0.4 (*)
Sulphur, wt ppm,max		2000	1000	

(*) Lead was subsequently phased-out in July 2001

4.5.4.7 Gasoline Specifications Trends in China

An unleaded grade was introduced in China from January 1st, 2000 (Standard Code GB 17930-1999). The specifications of this fuel are listed in Table 4.17.

Table 4.17: Unleaded Gasoline Specifications in China

	Limits
RON, min	90
(RON+MON)/2,min	85
Lead, g/l max	0.005
Manganese, g/l max	0.018
Benzene, vol.% max	2.5
Aromatics, vol.% max	40
Olefins, vol.% max	35
Oxygen, wt.% max	2.7
Sulphur, wt.ppm max	800
RVP summer, kPa max	74
RVP winter, kPa max	88

Comments:
As a general consideration, it can be observed that meeting these specifications is not imposing very severe restrictions on the refineries. In fact, a RON limit of 90 min must be met with compositional limitations of 40% max aromatics, 2.5% max benzene and 35% max olefins. This may mean that existing refineries (both topping-reforming and cat-cracking) can meet the specification with some addition of oxygenates in most cases. Also the sulphur specification of 800 ppm will be easily met by the simple refineries and should be within the reach of the cat-cracking refineries as well.

The quality of the other gasoline grades is regulated by standard GB 484-1993, which is still allowing the use of 0.35 to 0.45 g/l of lead.

4.5.4.8 Gasoline Specifications Trends in India, Pakistan, Bangladesh and Nepal
In all these countries the gasoline specifications are being tightened, albeit at different paces and to different levels of severity, with the aim of reducing vehicle emissions and improving urban air quality. Because of these differences, the gasoline specification trends are summarised in individual tables for each country as follows:

Table 4.18: India -- Metropolitan areas and other Large Cities
Table 4.19: India -- Rest of the Country
Table 4.20: Pakistan
Table 4.21: Bangladesh
Table 4.22: Nepal

4.5.4.8.1 INDIA

Table 4.18: Gasoline Specifications Trends in India - Metropolitan Areas (Source: ADB Workshop, New Delhi, May 2001) (Presented by Dr. A.A. Gupta)

	India Met.Areas 1996	India Met.Areas 2000	India Met.Areas 2005 (*)	India Met.Areas 2010 (*)
RON, min	87/93		91	93
Anti Knock Index (AKI), min	82	84		
Sulphur, wt.ppm max	1500	1000	150	150
Lead, g/l max	0.013	0.013	not detectable	not detectable
Benzene, vol.% max		5.0	1.0	1.0
Aromatics, vol.% max			40	35
Olefins, vol.% max			30	20
Oxygen, vol.% max		2.7	2.7	2.7

(*) Proposed

Table 4.19: Gasoline Specifications Trends in India -- Rest of the Country (Source: ADB Workshop, New Delhi, May 2001) (Presented by Dr. A.A. Gupta)

	India Rest of Country 1995	India Rest of Country 2000	India Rest of Country 2005 (*)	India Rest of Country 2010 (*)
RON, min	87/93		89	89
Anti Knock Index (AKI), min	82	84		
Sulphur, wt.ppm max	2000	1000	150	150
Lead, g/l max	0.56	0.013	not detectable	not detectable
Benzene, vol.% max		5.0	3.0	3.0
Aromatics, vol.% max			40	35
Olefins, vol.% max			30	20
Oxygen, vol.% max		2.7	2.7	2.7

(*) Proposed but not yet implemented

Comments:

a). Considering the big difference in traffic concentration, and hence in need to reduce emissions, between the large cities and the rest of the country, different specification levels and implementation timings are planned for the two situations.

b). In large cities the benzene content was envisaged to be reduced to the very low level of 1% (similarly to USA and Europe).

c). The sulphur content was envisaged to be reduced country-wide to 150 ppm by 2005, thus paving the way for the possible use of gasoline vehicles equipped with catalytic devices.

Indian refineries are in the process of developing strategies for upgrading their configuration in order to cope with the above specifications. The following new processes and/or modifications of existing units are being considered:

1) Splitting of reformer feed to remove benzene and its precursors
2) Hydrotreating of FCC gasoline (for cat-cracking refineries)
3) Isomerisation of light naphtha
4) Benzene saturation
5) Import or production of MTBE, TAME or other oxygenates, according to the attractiveness of local economics.

Some of these options are also relevant to the Sri Lankan refinery, and will be examined in detail in this study.

4.5.4.8.2 PAKISTAN

Table 4.20 provides a summary of the plan for moving to unleaded gasoline in Pakistan:

Table 4.20: Plan for Lead Elimination in Pakistan

	Pakistan 1999	Pakistan 2001	Pakistan 2003	Pakistan 2005
RON, min	80	87	87	87
Lead, g/l max	0.42	0.35	0.15	0
RVP, psi typ	9-10			
Sulphur, wt.ppm max	1000			
Benzene, vol.% max	<5.0			
Aromatics, vol.% max	<40			
T50, deg.C	125			
T90, deg.C	180			
End point, deg.C	205			

Comments:

a) the current plan foresees eliminating lead by 2005

b) the other gasoline characteristics to be eventually controlled have not yet been defined

Overall the situation of the refining industry in Pakistan is not very relevant to this study on the Sri Lankan refinery.

4.5.4.8.3 BANGLADESH

The plan for lead elimination in Bangladesh started in 1997 and was completed in July 1999 as shown in the following table:

Table 4.21: Lead Elimination in Bangladesh

	1997	1998	1999	2000
Approval of action plan	ok			
Regular grade lead, g/l	0.4	0.013	0.013	0.013
Other grades lead, g/l	0.4	0.4	0.013	0.013

Comments:

In Bangladesh lead was totally removed from gasoline in about two years.

4.5.4.8.4 NEPAL

Nepal is importing the totality of the country gasoline demand. The specification and typical qualities of gasoline for 1995 and 2000 are the following:

Table 4.22: Nepal Gasoline Quality

	Specification 1995	Typicals 1995	Specification 2000	Typicals 2000
RON	87	87	88	88.5
Lead, g/l	0.15	0.032	0.013	0.01
Sulphur, wt.ppm	2000	330	1000	300
Benzene, vol.%	n/a	3.0	5.0	2.6

Nepal's gasoline is now unleaded, but with a low octane quality - 88 RON.
Overall the situation of the petroleum industry in Nepal is not relevant to this study on the Sri Lankan refinery.

4.5.5 Actual Specifications Adopted Worldwide - Diesel Fuel

4.5.5.1 Reformulated Diesel Fuels in the USA

The emphasis of fuel reformulation in the USA has mainly been on gasoline, because of the very important role that this fuel plays in that market. However, more recently, attention has also been paid to the diesel fuel specifications, with the main aims of reducing PM and NOx emissions. Table 4.23 reports the current US Federal diesel specifications:

Table 4.23: Current US Federal Diesel Specifications

	US Federal current
Cetane Number, min	40
Or cetane index, min	40
Aromatics, wt.% max	35 (*)
Sulphur, wt.ppm, max	500 (**)
T90, deg.C max	338

(*) The limit in California is 10% max.
(**) The U.S. Environmental Protection Agency published the final rule for highway diesel sulphur control in Jaunary 2001. The rule limits sulphur in diesel to 15 ppn in 2006 -- to be enforced on about 80% of the fuel supply.
Density values of US diesel fuel typically range between 0.860 and 0.870

Comments:

a) As the vast majority (practically the totality) of US refineries have cat-cracking units (to maximise gasoline production) the cetane number of the diesel fuel has been traditionally low, and this is reflected in the above typical values. In fact the US diesel fuels are blended with significant quantities of cycle oils. However this practice, associated with a fairly tight limit on aromatics (35% Federal and 10% Californian), forced the refineries to invest in de-aromatization or hydro-cracking units. This significant reduction of aromatics obtained through hydrogen injection into the diesel fuel made the T90 value quite low (338 deg.C and below).
b) This low T90, together with low aromatics and a sulphur content not exceeding 500 ppm, ensures low emissions of fine particles from the exhaust of the diesel engines. Furthermore, in order to have in future an even larger reduction of particulates and sulphates emissions, the U.S. Environmental Protection Agency published the final rule for diesel sulphur control in January 2001, limiting the sulphur content of the diesel fuel down to 15 ppm beginning in 2006. Because of the very different structure of the US

refineries versus the situation in Sri Lanka, the above specifications can only give some very broad indications to guide this study.

4.5.5.2 Reformulated Diesel Fuels in the European Union

In Europe, the diesel fuel has traditionally plaid a very big role as a transportation fuel. In fact the diesel demand has been and still is at least as large as the gasoline demand. In this situation, the European legislators have given high priority to the control of traffic emissions (particularly particulate matter and nitrogen oxides) also through mandating tight diesel fuel specifications. The following Table 5.24 show that today the European Union specifications for diesel are the most advanced world-wide:

Table 4.24: Current and Future European Union Diesel Specifications

	EURO II 1996	EURO III 2000	EURO IV 2005
Cetane Number, min	49	51	51
Sulphur, wt.ppm, max	500	350	50
T95, deg.C max	370	360	360
Poly-Aromatics, wt.% max	n/a	11	11
Density @ 15 deg.C, max	0.860	0.845	0.845

Comments:

a) the high cetane number can be quite easily met by the topping-reforming refineries, but represents a severe problem for the cat-cracking ones, which have to invest in expensive de-aromatization and/or hydro-cracking units with associated hydrogen plants. These units are also necessary to satisfy increasingly severe poly-aromatics specification.

b) the sulphur limit of 50 ppm max foreseen for 2005 is consistent with the motor industry plan to introduce by that time new emission control technologies (such as de-NOx catalysts and regenerative particulate traps) which require fuel with very low sulphur levels. For this reason, the European Council is considering implementing a new sulphur limit of 10 ppm by 2009.

c) as already mentioned in section 5.4.2 of this chapter, in the countries of the European Union there are about 20 topping-reforming refineries, whose fuel reformulation experience is relevant to the situation in Sri Lanka.

These simple refineries rely heavily on straight-run gasoil to blend their diesel fuels. In meeting more and more stringent sulphur specifications (starting from original values approaching 5000 ppm about 20 years ago), they followed the following steps:

1) use of low sulphur crudes such as North Sea crudes or Arabian Light
2) invest in low to medium pressure hydro-desulphurization units (below 40/50 bar). This approach allows to meet sulphur concentrations of 2000 to 1500 ppm, in straight-run gasoils manufactured from Arab Light crudes.
3) Invest in high pressure hydro-desulphurization units (above 60/70 bar). This approach allows to meet sulphur concentrations around 300/200 ppm, in the same gasoils mentioned above.
4) the limit of 50 ppm is likely to require investments in hydro-crackers plus hydrogen plants. These units are fully consistent with the long term needs of European refineries, geared to maximising the production of distillates.

This sequence of sulphur reduction measures is relevant to the current study.

4.5.5.3 Tightened Diesel Specifications in Australia/Japan/Korea

All three countries have moved to tighter diesel fuel specifications recently. Table 4.25 shows the main specifications either already implemented or planned between now and 2005.

Table 4.25: Current and Future Diesel Fuel Specifications in Australia/Japan/Korea

	Australian 1999	Australia 2003	Japan 2000	Japan 2007	Korea 2000	Korea 2002
Cetane Number, min	45	49	50	52	45	50
Sulphur, wt.ppm, max	1500	500(*)	500	50(**)	500	300
T90, deg.C max	357		360	360		
T95, deg.C max		360			360	360
Aromatics, wt.% max				(**)		30
Poly-Aromatics, wt.% max		11		10 (**)		
Density @ 15 deg.C	0.870	0.845	0.860	0.845 (**)	0.860	0.845

(*) plan to reduce to 50 ppm in 2006;
(**)under discussion

Comments:

a) a further reduction of the sulphur level to 50 ppm is under review in Australia for the year 2006.
b) the diesel fuel specifications of these countries, which in the past were based on the US concept, are moving from 2002 onwards to the European Union approach, in terms of:
    1) Cetane numbers at or exceeding 50
    2) sulphur content moving below 500 ppm (and likely to go down to 50 ppm in Japan and Australia)
    3) use of the T95 instead of the T90 specification, as being more relevant to PM control
    4) use of the Poly-Aromatics instead of the total Aromatics specification, as being more relevant to PM control
    5) lower density values - around 0.845 - to control particulate emissions from light duty indirect injection engines
c) in terms of refining approaches to meet the above specifications, some topping-reforming Australian plants follow similar measures to those mentioned above for Europe. The other refineries are large complex plants, which have already invested, or are planning to invest, in high-pressure hydro-desulphurization/hydro-dearomatization and/or hydro-cracking units.

As regards this study, the comments made under point 4.5.5.2 still apply.

4.5.5.4 Proposed Guideline Diesel Specifications in Latin America and the Caribbean

A common set of key technical specifications for transport fuels has been proposed for application throughout Latin America and the Caribbean. Although it is the prerogative of individual countries to set national standards at levels they consider appropriate, these

proposed specifications are intended as minimum standards throughout the region. These proposed guideline specifications for diesel fuel are listed in Table 4.26.

Table 4.26: Proposed Guideline Diesel Specifications for Latin America and the Caribbean (issued in 1998)

Specification	Value 2001	Value 2005
Cetane Number, Typ.	45	47
Sulphur, wt.ppm, max	5000	2000
T90, deg.C max	360	360
Aromatics, wt.% max	30	30
Density @ 15 deg.C	0.820 to 0.860	0.820 to 0.860

Comments:

These guideline specifications are less severe than those reviewed so far for USA, EU, Australia, Japan and Korea. However they represent a good starting point, as minimum standards, for the developing economies of Latin America and the Caribbean. In particular, the following is worth noting:

a) the cetane numbers are more in line with those in the USA than those typical in Europe
b) by 2005, the sulphur content will be lowered to 2000 ppm. This limit is not severe in absolute, but recognises the high sulphur crude slate of this region.

In the Latin American and Caribbean countries there is a range of refineries from simple topping-reforming to more complex cat-cracking ones. Planning studies have identified the investments needed for each refinery type to comply with the above specifications:

Topping-reforming refineries	Cat-cracking refineries
Dist. Cut point in CDU (for T90 & Density specs)	Dist. Cut point in CDU (for T90 & Density specs)
Low/Med pressure de-sulphurization units	Med pressure de-sulphurization units
Use of cetane improver additives	Use of cetane improver additives
	De-aromatization units

This is consistent with the approach followed by topping-reforming refineries world-wide, and is also relevant to the conditions in Sri Lanka.

4.5.5.5 Proposed Guideline Diesel Specifications for Countries in Central Asia and the Caucasus

The UNDP and the World Bank (Energy Sector Management Assistance Programme) have jointly sponsored a study on "Cleaner Transport Fuels for Urban Air Quality Improvement in Central Asia and the Caucasus". As part of this study, limits for diesel fuel sulphur were proposed for this Region, as shown in Table 4.27.

Table 4.27: Proposed Guideline Diesel Specifications for Countries in Central Asia and the Caucasus (issued in 2001)
(The timing should be re-assessed in a few years)

Fuel Parameters	Type II grade current	Type I grade current	Single Grade 2005	Single Grade 2015
Sulphur, wt.ppm,	5000	2000	2000	500

Comments:

a) as a first step it is recommended to tighten only one specification, namely the sulphur content. This measure would bring about significant benefits in terms of both particulates and sulphates emissions.

b) the planned approach for meeting this specification includes continuing to refine lower sulphur crudes and investing in low to medium pressure diesel hydro-desulphurization plants.

4.5.5.6 Recent Diesel Specifications in South East Asian (S.E.A.) Countries

Most SEA countries have been very active, over the last 5 to 10 years, in tightening their national diesel fuel specifications, with the aim of mainly reducing particulate emissions from transport sources. The current situation for Singapore, Malaysia, Thailand and the Philippines is as follows:

Table 4.28: Recent Diesel Specifications in South East Asian (SEA) Countries

	Singapore 2000	Thailand 1999	Philippines 2001	Philippines 2004	Hong Kong 2001
Cetane Number, min	48	49	48	48	51
Sulphur, wt.ppm, max	500	500	2000	500	350
T90, deg.C max	357	357	357	357	
T95, deg.C max					360
Poly-Aromatics, wt.% max					11
Aromatics, wt.% max		30 (*)			
Density @ 15 deg.C, max	0.87	0.810 to 0.890	0.865	0.865	0.845

(*) Typical value

Comments:

In 2001, Hong Kong introduced a 50 ppm diesel fuel, with a government' s tax incentive of 40 cents per gallon. The refineries in this region, and particularly in Singapore, Malaysia and Thailand, are quite complex and have a sizeable level of conversion capacity. Therefore their challenges and their solutions in meeting the above specifications are not very relevant to a topping-reforming refinery. However, as far as producing advanced diesel fuel is concerned, they are mainly investing in high pressure hydro-desulphurization and hydro-aromatization units, as well as hydro-crackers. Some limited data is available from other South East Asian

countries, mainly regarding sulphur, cetane index and density, as shown in the following additional Table 4.29.

Table 4.29: Diesel Fuel Specifications in Other S.E.A. Countries

	Brunei 2000	Indonesia 2000	Myanmar 2000	Vietnam 2000
Density @ 15 deg.C, max	0.870	0.870		0.860
Cetane Index, min	47	45	47	45/ 50
Sulphur, wt.ppm, max	2500	5000	3000	5000

It is obvious that, in these countries, no substantial measures have been taken as yet to tighten the specifications of the diesel fuels that are either imported or manufactured locally.

4.5.5.7 Diesel Fuel Specifications Trends in China

An improved premium diesel fuel grade will be introduced in China from January 1st, 2002 (Standard Code GB 252-2000). The specifications of this fuel are listed in Table 4.30.

Table 4.30: Diesel Fuel Specifications in China

	Normal grade	Premium grade
Cetane Number, min	40	45
Sulphur, wt.ppm, max	5,000 to 10,000	2,000
Ash, wt.% max	0.02	0.01
CCR 10%, wt.% max(*)	0.3	0.3
Acidity, mgKOH/100ml,max	10	5

(*) CCR is the Conradson Carbon Residue of a diesel fuel, and it indicates the tendency of the fuel to form carbonaceous deposits. High values denote a high tendency to deposit formation

The new Premium grade (from 2002) is the first significant step towards improving the diesel fuel quality.

4.5.5.8 Diesel Fuel Specifications Trends in India, Pakistan, Bangladesh and Nepal

In all these countries the diesel fuel specifications are being tightened, albeit at different paces and to different levels of severity, with the aim of reducing vehicle emissions and improving urban air quality. Because of these differences, these specification trends are summarised in individual tables for each country as follows:

Table 4.31: India - Metropolitan areas and other Large Cities
Table 4.32: India - Rest of the Country
Table 4.33: Pakistan
Table 4.34: Nepal

4.5.5.8.1 INDIA

Table 4.31: Diesel Specifications Trends in India -- Metropolitan Areas (Source: ADB Workshop, New Delhi, May 2001)

	India Met.Areas 1998	India Met.Areas 2002	India Met.Areas 2005 (*)	India Met.Areas 2010 (*)
Cetane Number, min	45	48	50	51
Sulphur, wt.ppm, max	2500	500	500	150
T95, deg.C max	n/a	370	370	360
Poly-Aromatics, wt.% max	n/a	N/a	11	9

(*) target

Table 4.32: Diesel Specifications Trends in India -- Rest of the Country (Source: ADB Workshop, New Delhi, May 2001)

	Rest of the Country 1995	Rest of the Country 2002	Rest of the Country 2005 (*)	Rest of the Country 2010 (*)
Cetane Number, min	45	48	50	51
Sulphur, wt.ppm, max	10,000	2500	500	350
T90, °C, max	366	n/a	n/a	n/a
T95, deg.C max	n/a	370	370	360
Poly-Aromatics, wt.% max	n/a	n/a	11	9

(*) target

Comments:

a) India tends to follow the European approach in terms of type of specifications (e.g. T95 and Poly-aromatics) and values, albeit with a few years delay.

b) The only difference between the fuels for the Metro Areas and the rest of the Country is the sulphur content. By 2002 the Metro areas should have the same sulphur level that the USA and Europe had in 1993/1996 (i.e. 500 ppm)

c) The future sulphur and cetane levels will require high severity hydro-desulphurisation and hydro-dearomatisation units (or hydro-cracking units which would give the refiners full flexibility to meet the above specifications with any crude, but which are likely to require hydrogen generating plants).

4.5.5.8.2 PAKISTAN

The first step in diesel fuel reformulation is foreseen in Pakistan at the end of 2002, and it will involve a sulphur reduction from 10,000 to 5,000 ppm, as shown in Table 4.33:

Table 4.33: Diesel Specifications Trends in Pakistan
(Source: ADB Workshop, New Delhi, May 2001)

	Current Limits	Dec. 2002 Limits
Cetane Number, min	45	45
Sulphur, wt.ppm, max	10,000	5,000
Ash, wt.%	0.01	0.01
CCR,%	0.10	0.10

4.5.5.8.3 BANGLADESH

A reduction of the sulphur content of the diesel fuel to 2,500 ppm is being examined, but no firm plans have been agreed yet.
(Source: Dr. S.M. Salehuddin' s presentation at the ADB Regional Workshop held in New Delhi in May 2001)

4.5.5.8.4 NEPAL

The quality of the imported diesel fuel has been tightened from 1995 to 2000. These changes are summarised in the following Table 4.34:

Table 4.34: Nepal Diesel Fuel Quality
(Source: ADB Workshop, New Delhi, May 2001)

	Specification 1995	Typicals 1995	Specification 2000	Typicals 2000
Cetane Number, min	42 to 45	42	48	42.7
Sulphur, wt.ppm, max	10,000	n/a	2,500	1,900
Ash, wt.%	0.01	0.005	0.20	0.007
CCR,%	0.35	0.20	0.30	0.17

The actual Cetane quality appears to be quite low, while the typical value of the Sulphur content is below 2000 ppm, which is a very good starting point towards a gradual improvement of the diesel fuel quality.

4.5.6 Fuel Reformulation -- Energy Use and CO_2 Emission Implications

In all fuel reformulation cases just described, the imposition of more restrictive gasoline and diesel fuel specifications was calculated to generate an increased use of energy in the refinery processes, and hence increased CO_2 emissions during the refinery operations. An indicative quantification of such an increase emerges from the conclusions of a study

carried out by CONCAWE in 1995, reflecting the average impact of more severe fuel specifications on the fuel consumption of about 100 European refineries. The results of this study are summarised in the following table, and they have to be interpreted as average, typical data across a broad range of refinery configurations and operations:

Table 4.35: Fuel Reformulation and Refinery Energy Consumption

	Base Case	Fuels reformulation Severity Level 1	Fuels reformulation Severity Level 2	Fuels reformulation Severity Level 3
Gasoline Pool:				
RON (Clear)	92	93.5	95	95.6
Lead g/l	0.37	0.17	0.013	0
Benzene, % max	5.0	5.0	3.0	1.0
Aromatics, % max	45	42	40	30
Distillate:				
Ind. Gasoil, S %	0.5	0.3	0.1	0.1
Diesel, S %	0.2	0.15	0.05	0.05
Pool, S %	0.41	0.23	0.07	0.07
Cetane Number	50.0	50.0	52.0	53.5
Fuel Oils (Including Bunker):				
Pool, S %	2.44	2.29	1.83	1.61
% Increased refinery energy Consumption and consequent additional CO2 emissions	**0**	**10**	**22**	**40**

Based on this information, the specification changes suggested in the next section of this chapter (Section 5.7) would entail for the Sapugaskanda refinery an energy consumption increase in the range of 10% to 15%.

4.5.7 Options for Sri Lanka -- A Plan for Cleaner Fuels

The above analysis of:

a) The major transport fuel reformulation that have taken place in the last 20 years

b) The rationale behind all most significant specification changes

c) The measures taken by refineries world-wide to cope with the above changes gave some very important directions regarding the best course of action to be followed in Sri Lanka, taking into account the structure of the local refinery (topping-reforming), and the local product slate, product demand and product quality. In terms of product quality, the following fuel specifications should be tightened to move towards "modern" transport fuels, that are viable in the short to medium range:

gasoline:
- top priority: lead content (already implemented in 2002), benzene
- other priorities: aromatics, front-end-volatility (RVP)

- for the time being, less attention should be paid to the sulphur and the olefins contents because they are already quite low as in most typical topping-reforming refineries.

diesel fuels:
- top priority: sulphur content
- other priorities: back-end-volatility (T95) and density
- for the time being, less attention should be paid to the cetane number, which is already now quite high, and the aromatics content, which are already low, as the diesel fuel is mainly blended with straight-run gasoil.

However, while assessing the various case studies, all these fuel parameters will be monitored to ensure that they will continue to be within acceptable limits, and their values will be calculated and reported for each case study.

Based on these fuel reformulation priorities, the following considerations can be made regarding refinery modifications and investments, for the Sapugaskanda refinery:

a) As fuel quality requirements become tighter, it is increasingly difficult for small, simple topping-reforming refineries to meet the new fuel specifications, because of the economies of scale involved in investing in additional expensive process units. In fact currently the only option for the Sapugaskanda refinery, in the face of lead elimination, would be to blend gasoline with straight-run naphtha and reformate, the latter providing the bulk of the octane required.

b) The consequence of this would be gasolines with increasing amounts of aromatics.

For these refineries, limiting benzene and aromatics rules out the present approach of relying only on reformate to compensate for the octane shortfall consequent to the lead elimination. Other sources of octane such as cat-cracker naphthas, isomerates and oxygenates must be considered.

c) Considering the relative market demands for gasoline and diesel fuel in Sri Lanka, the two most serious contenders for the Sri Lankan refinery appear to be a new isomerization unit or/and the purchase of high octane blending components such as oxygenates or higher octane unleaded gasoline to be used in the final blends. The selection of either of the two is clearly depending on local economics.

d) The cat-cracker does not look attractive for Sri Lanka as this process, on top of its high cost, is particularly suitable for maximising naphtha production. This does not appear to be a pressing need for Sri Lanka, where local gasoline production is practically in line with market demand, while there is a large distillate shortfall. For this reason a process aiming at the conversion of fuel oil to mainly distillate should be considered. One obvious candidate for this purpose, now very popular world-wide, is the hydro-cracker, which has the big benefit of providing large flexibility in meeting severe diesel fuel specifications (at the level of EURO II/III), without imposing costly limitations on the refinery crude slate. Furthermore a hydro-cracking unit would not require to make more severe the current operating conditions of the hydro-treating plants of the Sapugaskanda refinery.

In summary, the following process options will be assessed in this study, in terms of investments and total costs, as future possible options for Sri Lanka.

Unleaded Gasoline:
- short range (up to 2005): use the availble blending component, and import enough 90 RON gasoline to meet market demand
- longer range (2010--2015): invest in an isomerization plant to:
- upgrade the light naphtha from about 67/69 RON to 83 RON
- reduce/avoid dependency on expensive MTBE
- increase flexibility in meeting RON, Benzene/Aromatics specifications
- sensitivity case: use of MMT to achieve an octane lift of up to 1 RON (the rationale for the selection of the value of 1 RON is given in Section 4.7.3.1).

Diesel fuels:
- short range (up to 2005): maximise the utilisation of the existing hydro-treating capacity aiming at achieving at least a sulphur level of 2,500 to 3,000 ppm, and use more low sulphur crude.
- longer range (2010--2015): invest in a hydro-cracker to: a) produce more distillate and move the refinery production closer to market demand, and b) give the refinery full flexibility to meet lower sulphur and other future diesel fuel specifications (with this investment, fuel qualities like those postulated by EURO II/III and/or World-Wide Fuel Charter -- Diesel Category 2 will become feasible). As an alternative, if the Asian market conditions are not favouring large refinery investments, the possibility of importing low sulphur diesel fuel blending components or finished products should be considered.
- sensitivity case: expand capacity and increase severity of the hydro-treating plant, in order to meet a sulphur specification approaching 500 ppm.

4.6. ANALYSIS OF CURRENT REFINERY OPERATION AND SELECTION OF CASE STUDY

4.6.1 Study Approach

Section 4.5.7 lists the fuel parameters to be tightened and the new processes that are needed to satisfy the tighter specifications. They are:

gasoline:
- top priority: lead content (already implemented in 2002), benzene
- other priorities: aromatics, front-end-volatility (RVP)
- for the time being, less attention should be paid to the sulphur and the olefins contents because they are already quite low now as in most typical topping- reforming refineries).

diesel fuels:
- top priority: sulphur content
- other priorities: back-end-volatility (T95) and density
- for the time being, less attention should be paid to the cetane number, which is already now quite high, and the aromatics content, which is already low, as the diesel fuel is mainly blended with straight-run gasoil.

To carry out the study, target values for each of the above fuel qualities had to be defined. At a meeting of the Project Management Unit held in Colombo in the week of the 14th of January 2002, the study targets were debated, and the values of Table 4.36 were agreed in principle.

Table 4.36: Fuel Quality - Study Targets

	Gasoline 2005	**Gasoline 2010**	**Gasoline 2015**
RON (gasoline pool), min	90 (*)	90 (*)	90 (*)
Lead, g/l max	0.013	0.008	0.005
Benzene, vol. %, max	4.0	3.0	2.0
Aromatics, vol. %, max	45	45	40
RVP, kPa, max	60	60	60
	Diesel Fuel (**) 2005	**Diesel Fuel 2010**	**Diesel Fuel 2015**
Sulphur, wt. ppm, max	3000	1000	500
T95, deg.C, max	380	380	365
Density, kg/m^3, max	860	860	860
Cetane index, min	46	46	50
Cetane number, min			
Poly-aromatics, wt% , max	12	12	5

(*) The study assumed that the 95 RON unleaded grade will continue to be imported
(**) The study assumed that the Super Diesel grade will continue to be imported

The refinery processe options, which will be considered in this study in order to satisfy the above fuel quality targets, have been discussed in section 4.5.7.

These process options will be assessed in detail in this study, calculating for each of them individually, or in appropriate combinations:

a) investments costs.
b) incremental fixed and variable operating costs.
c) cost of high quality purchased blending components (e.g. MTBE).
d) product quality implications, i.e. calculated values of the most important gasoline (RON, MON, RVP, Aromatics, Benzene) and diesel fuel (Sulphur, Cetane, T95, Density, Aromatics) specifications.
e) impact of the above specification changes on the total emissions of the vehicle population of Sri Lanka, and hence likely impact on air quality.

4.6.2 Country Product Demand

The total product demand for Sri Lanka, for the period 1990 to 2000, is shown in the following Table 4.37.

Table 4.37: Petroleum Product Demand for Sri Lanka

	1990	1992	1994	1996	1998	2000
90 RON Gasoline, t/y	178,945	162,433	180,690	194,972	201,281	224,374
Auto Diesel, t/y	511,120	604,524	725,733	942,700	1,115,400	1,316,200
Gasoline/Automotive Diesel ratio	0.35	0.27	0.25	0.21	0.18	0.17
Jet Kerosene, t/y	118,339	131,182	146,774	195,282	199,950	259,452
Other Kerosene, t/y	167,241	189,373	207,991	228,389	235,909	227,789
Furnace Oil, t/y	157,774	254,942	282,137	341,464	556,048	736,705
LPG, t/y	34,900	44,700	63,600	87,000	117,000	140,000

The gasoline/diesel ratio is unusually low, indicating that the gasoline demand is a small component of the product slate. The data show that this trend was accelerated in the mid to late 1990s, most likely because of a fuel tax policy which favoured diesel versus gasoline. The diesel fuel has the highest demand among all petroleum products. An analysis of the major marketing outlets for this product is reported in Table 4.38.

Table 4.38: High Speed Diesel Demand by Sector (Transport versus Others)

	High Speed Diesel , t/y			
	Total Demand	Transport	Others (*)	% Transport
1990)	511,120	480,716	30,404	94.1%
1991)	537,975	502,550	35,425	93.4%
1992)	604,524	566,373	38,151	93.7%
1993)	664,730	624,175	40,555	93.9%
1994)	725,733	678,832	46,901	93.5%
1995)	788,898	739,968	48,930	93.8%
1996)	1,045,695	829,198	216,497	79.3%
1997)	1,294,731	908,425	386,306	70.2%
1998)	1,187,138	1,004,272	182,866	84.6%
1999)	1,376,772	1,102,704	274,068	80.1%
2000)	1,683,523	1,316,200	336,705	80.0%

(*) Others include industrial, commercial, agricultural and power generation applications

The data show that, while the transport diesel demand grew at a rate of about 16% per year over the period 1995/2000, the diesel demand for other applications grew at an even faster rate over the same period. It is important to keep this point in mind, when, in future, diesel fuel specifications will become tighter. In fact, if the "other" applications will not require the same advanced (and expensive) quality of the transport fuel, the possibility of marketing two diesel fuel grades should be seriously considered, provided that adequate infrastructure exists to handle two types of diesel during distribution and storage.

4.6.3 Sapugaskanda Refinery: Facilities and Crude Slate

Sapugaskanda is a topping-reforming refinery with hydro-treating units for naphtha, kerosene and diesel fuel. A visbreaker is providing some conversion capacity, but not enough to get even close to the distillate market demand of Sri Lanka. Hydrogen production is predominately from naphtha reforming, which limits application of severe hydro-desulphurization and hydro-cracking units. Hydro-crackers or severe high pressure hydro-desulphurization units would need to be complemented by a hydrogen generating plant. The installed capacities of the various units are shown in the following table:

Table 4.39: Process Capacity of Sapugaskanda Refinery

Processes	Crude Distillation t/cd	Vacuum distillation t/cd	Catalytic Reforming t/cd	Catalytic Hydrofining t/cd	Catalytic Hydrotreating t/cd	Diesel Hydrotreating t/cd	Visbreaking t/cd
Refining Capacity	6900	350	650	1000	1100	350	1900

The capacities of the units shown are the design capacities.

As an illustration of the yields of these refinery units, the 1999 refinery production has been as follows:

Table 4.40: Production of Finished Products in 1999

Products	1999 t/c.day	1999 t/y
87 RON UnleadedGasoline	759	277,035
Diesel fuel	2225	812,125
Gasoline/Diesel ratio	0.34	
Total Kerosene	976	356,240
Furnace Oil	2373	866,145
LPG	54	19,710
Chemical Feedstock	232	
Bitumen	240	

By comparing the content of this table to the total product demand shown in Table 4.37, it is obvious that, with gasoline production and demand close to balance and with an excess Furnace Oil production, the overall economics would benefit, in the long range, from investing in a conversion unit geared towards distillate production, e.g. a hydro-cracker.

4.6.3.1 Crude Slate

The major crude oil components of the crude slate processed in the Sri Lankan refinery are Iranian Light, Arabian Light, Upper Zakum and MIRI. The average proportion of each crude in the slate and the main characteristics of each crude are shown in Table 4.41.

Table 4.41: Properties of Crude Oils Processed at Sapugaskanda

Crude Oil Type	Iranian Light	Arabian Light	Upper Zakum	MIRI
Average % in Crude Slate	50	20	10	20
API Density	33.0	33.4	33.1	32.6
Sulphur, wt %	1.35	1.8	2.0	0.2
Diesel Cetane Index	53	53	52	43
Diesel Pour Point, deg.C	-3.2	-8.0	2.2	-8.1
85-180 deg.C, wt %	13.4	14.5	13.4	18.0
120-230 deg.C, wt %	17.2	19.0	20.0	22.0
180-350 deg.C, wt %	29.4	31.0	30.8	48.8

These crudes are already fairly low sulphur. Therefore there is only limited scope for significant reductions of product sulphur (e.g. in diesel fuel) via moving to a lower sulphur crude slate. There appears to be some scope for replacing the highest sulphur crudes (in the 1.8 to 2.0% range) with more lower sulphur MIRI crude. However the scope is limited,

because of the very low cetane quality of the gasoil produced with this crude. Furthermore, the MIRI crude gives higher gasoline yields, as it can be seen from the crude distillation characteristics. While the computation of this effect was beyond the scope of this study, its impact on the overall refinery product slate (and hence the financial returns of the refinery operation) cannot be ignored.

4.6.3.2 Quality of Today's Refinery Blending Streams

The above sections of this chapter concentrated mainly on the volumes of product manufactured and the installed capacities of the existing refinery units. Another important input for this study is the performance of the individual refinery plants, in terms of the quality of the blending streams, for both gasoline and diesel, they are capable of producing. The key qualities of the blending components for gasoline and diesel fuel are reported in Tables 4.42 and 4.43 respectively.

Table 4.42: Properties of Gasoline Blending Components

	Virgin Naphtha (*)	Visbreaker Naphtha (*)	Cat. Reformed Naphtha
RON	67	55	94.0
Sulphur, ppm	1	1	0.5
Specific Gravity	0.67	0.71	0.785
RVP, kPa	82.7		37.9
Aromatics, %	1.5		52
Benzene, %	1.0		2.0

(*) After hydro-treating

Table 4.43: Properties of Diesel Fuel Blending Components

	Straight-run Gasoil	Visbreaker gasoil
Sulphur, ppm	9000	13500
Density @ 15 deg.C, kg/lt	0.855	0.875
95% Distillation point	380	395

Comments:

- Both the visbreaker naphtha and gasoil are not good blending components, but they are produced in fairly low quantities.
- The main gasoline blending components are quite good. Of particular notice are the very low sulphur and benzene values, due to the particular operating procedures followed in the Sri Lankan refinery. Also the aromatics content of the reformate is not particularly high.
- The octane values of the virgin naphtha and the reformate are typical of these streams, and are not sufficient for achieving a 90 RON minimum in the finished blended product, in quantities necessary to satisfy in full the market demand.

- As regards the diesel fuel components, their high sulphur levels are of concern. These streams will need severe hydro-treating in order to meet the anticipated future sulphur limits for the diesel fuel.

4.6.4 Future Product Demand - 2005 to 2015

The following approach was used to estimate product demand up to 2015:

a) **Land Transport Fuels**: a mathematical model was used to calculate fuel usage by year and by fuel on the basis of the following data inputs: estimates of vehicle population increase for each main type of vehicle, average vehicle population age (to calculate the rate of old vehicles which will be retired from the market during the period and hence the total registrations of new vehicle technologies), pattern of vehicle use in terms of average annual mileage and average speed. This information, combined with automotive industry published data on average fuel consumption for each type of vehicles, allowed to calculate an estimation of the fuel needs for each year between 2000 and 2015. Historical data from 1990-2000 was used to calibrate and validate the model.

   As regards the mix of gasoline and diesel light duty vehicles, two scenarios were assessed:

   One) proportionally more gasoline engine vehicles will enter the market at the expense of diesel vehicles

   Two) trend of the last ten years to continue also over the period up to 2015

b) **Jet Kerosene**: demand for this fuel was assumed to grow with the same trend of the last five years (1995 to 2000)

c) **Other Kerosene, Furnace Oil, LPG:** demand for this fuels was assumed to grow with the same trend of the last 5 years (1995 to 2000).

The predictions of these calculations and assumptions are shown in the following two tables.

Table 4.44: Estimated Product Demand - Scenario One: Gasoline Demand Grows Faster at the Expense of Diesel

Products	2000 (Actual)	2005	2010	2015
90 RON Gasoline, t/y	224,374	340,000	530,000	790,000
Auto Diesel, t/y	1,316,200	2,000,000	2,600,000	3,250,000
Gasoline/Automotive Diesel ratio	0.17	0.17	0.20	0.24
Jet Kerosene, t/y	259,452	325,000	400,000	510,000
Other Kerosene, t/y	227,789	270,000	330,000	390,000
Furnace Oil, t/y	736,705	840,000	900,000	950,000
LPG, t/y	140,000	150,000	165,000	180,000

Table 4.45: Estimated Product Demand - Scenario Two: Gasoline and Diesel Growth trend of the last 5 years to Continue

Products	2000 (Actual)	2005	2010	2015
90 RON Gasoline, t/y	224,374	280,000	345,000	425,000
Auto Diesel, t/y	1,316,200	2,100,000	2,800,000	3,600,000
Gasoline/Automotive Diesel ratio	0.17	0.13	0.12	0.12
Jet Kerosene, t/y	259,452	325,000	400,000	510,000
Other Kerosene, t/y	227,789	270,000	330,000	390,000
Furnace Oil, t/y	736,705	840,000	900,000	950,000
LPG, t/y	140,000	150,000	165,000	180,000

The above data show that, in both scenarios, the diesel fuel continues to be by far the one with the highest demand. This is due to the impact of various effects:

a) There is a large existing vehicle population equipped with diesel engines that will continue to use diesel fuel. A significant fraction of this existing vehicle population will last beyond the study horizon year of 2015.
b) Tax schemes aiming at deterring large scale switching from gasoline to diesel vehicles are only affecting the light duty vehicle segment of the market (i.e. passenger cars, vans and similar vehicles with engine displacements up to 3 litres maximum). Buses and lorries will continue to be equipped with diesel engines. Furthermore these latter vehicles are high fuel consumers for two obvious reasons: they have larger engines and they tend to run more miles than the light duty vehicles.
c) At least 20% of the total diesel fuel demand is used in applications other than transport (see Table 4.38), and these segments of the diesel fuel demand cannot be replaced by gasoline.

However, Tables 4.44 and 4.45 show that fiscal measures that would divert new purchases of light duty vehicles towards gasoline engines from 2002/2003 are bringing the gasoline to diesel demand ratio more in line with that of other Asian countries.

Nevertheless Sri Lanka will continue to be a net importer of diesel fuel for many years to come, while, with some targeted investments, the Sri Lankan refinery could satisfy the local demand for gasoline.

The estimated future demands of Tables 4.44 and 4.45 will be compared against the predicted gasoline and diesel fuel production of each case study.The remainder of the study will focus on meeting demand for auto diesel, and not high speed diesel as a whole.

4.6.5 Selection of Case Studies

Considering the combination of refining capacity, market demand, fuel quality targets and refining processes to be evaluated, the following case studies will be fully assessed in terms of investment and operating costs, product quality of a broad range of fuel parameters as well as impact of these fuel quality changes on the emission of the key pollutants:

Table 4.46: Case studies

		Cases # 1a to 1i	Cases # 2a to 2f	Cases # 3a to 3b	Cases # 3c to 3l	Cases # 4a to 4b	Cases # 4c to 4l	Cases # 5a to 5f	Cases # 5g to 5r
Refining Capacity:	Current	x	x	x	x				
	Double					x	x	x	x
Processes:	Debottlenecking & expansion of the existing hydrotreating capacity	x	x	x	x	x	x	x	x
	New Isomerization		x	x		x		x	
	New Hydrocracker			x	x (*)	x	x (**)		
	New High severity (70 bar) hydrotreating plant							x	x (***)
Blending Products:	**Gasoline** : use combination of MTBE, MMT and 95 RON unleaded gasoline	x	x	x	x	x	x	x	x
	Diesel:								
	Use of Low S crude, % of slate	x							

(*) several Hydro-cracker capacities are explored between 850,000 and 1,100,000 t/y

(**) several Hydro-cracker capacities are explored between 1,500,000 and 2,000,000 t/y

(***) several HP hydro-treating plant capacities are explored between 800,000 and 1,100,000 t/y

These case studies have been selected in order to separate the effects on costs and product quality of the fundamental variables of the study, i.e. refining capacity, product demand, fuel quality targets and selection of future, potential, additional refinery units. In total a combination of 57 between original cases and sensitivity cases will be studied and reported in section 4.5.7.

4.7. DISCUSSION OF REFINERY CASE STUDY

4.7.1 Methodology

The case studies will be presented and discussed in increasing order of complexity and cost of refinery investments and operations, as follows:

a) within the existing refining capacity, maximise the utilisation and expand the current gasoil hydro-treating units, explore the implications of processing lower sulphur crudes and of the use of a variety of gasoline blending components such as MMT, MTBE and high RON unleaded gasoline.
b) addition of an isomerization plant with a capacity of 100,000 t/y to the situation described in a).
c) addition of a hydro-cracker plant with capacity varying between 850,000 and 1,100,000 t/y to the situation described in b).

The following two Sensitivity cases, assessing the implications of doubling the exiting refining capacity were studied.

d) assuming to double the existing refining capacity, add both an isomerization plant with a capacity of 150,000 t/y and a hydro-cracker plant with capacity varying between 1,500,000 and 2,000,000 t/y. Explore also the implications of using a range of high octane gasoline blending components.
e) within the situation described in d), the hydro-cracker has been replaced by a High Pressure (HP) hydro-treating plant (operating pressure higher than 70 bar) to reduce drastically the sulphur content of the gasoil. A range of capacities for this plant has been explored (from 800,000 to 1,100,000 t/y).

The results of each of these case studies will be presented individually, and discussed according to logical groupings, i.e. discussing together each major case and the sensitivity cases derived from it. For each individual major case and sensitivity case, the following detailed information will be given:

1) Capital investment costs.
2) Fixed operating costs and variable operating costs associated to the investments in 1).
3) Other operating costs due to the use of specially imported blending components (MMT, MTBE, 95 RON gasoline) or to the use of low sulphur crudes.
4) Volume of MTBE or 95 RON unleaded gasoline used in the product blend.
5) Additional cost of the transport fuels consequent to the costs incurred in 1), 2), 3). For this calculation, it is assumed that the additional costs 1), 2), 3) are incurred only because of the need to improve the quality of the transport fuel; therefore these costs are only allocated to gasoline and diesel fuel and they are expressed in Rs./lt.
6) Production of gasoline and diesel fuel and availability of naphtha for export or use as a chemical feedstock.
7) Key qualities of the gasoline produced (RON, MON, RVP, Aromatics content, Benzene Content). Also the Olefins and Sulphur content of the gasoline were calculated. However, for sake of simplicity, they have not been reported, as, in all cases, they were very low.

8) Key qualities of the diesel fuel produced (Sulphur, Cetane Index, T95, Density and Poly-aromatics). These parameters are those that, according to comprehensive US and European studies, emerged as the key parameters affecting the level of exhaust emissions from diesel engines.

An industry standard linear programming model, adapted to represent the structure of the refinery in Sri Lanka, was used to calculate the yields of the various processes. Product quality mass balances and costs of each case study were calculated through the use of spread-sheets. All calculations were made for product pools (i.e. no attempts were made to identify and separate possible product grades). The refinery investments have been estimated on the assumption that the refinery would always be run to the limitation of the crude distillation unit.

4.7.2 Cost Inputs

The capital costs for the processes that will be considered in this study are those quoted by major international process vendors for the geographical area in question. Therefore they are inclusive of an average location factor. These costs have been also compared to costs adopted in similar studies world-wide, to ensure relative consistency (of course apart from the location factors). In particular, a consistent set of cost data used in the European Union Auto-Oil II programme proved quite useful. This study was performed for Directorate General XVII of the European Union by independent consultants. The process cost data for this study were extensively searched and came from a variety of sources, among which: UOP, IFP, AKZO NOBEL, CDTech Houston, CRITERION Catalyst UK, EPA, ETHYL Corp., STRATCO USA, Sud-Chemie Germany, CONCAWE and several petroleum industries.

For the calculation of the costs of the processes included in the present study (and of their implications in terms of product cost) the following assumptions were made:

- Location Factor: 1.4 across all processes
- Scaling Factor: power of 0.6
- Annualization of capital costs: the capital costs were annualised over 10 years, with a discount factor of 7%
- Operating costs associated with the investment: 5 % of annualised capital costs
- Cost of tankage, utilities, infrastructure, etc.: 20% on top of total local cost

Regarding the actual investment costs, the following Table 4.47 gives a summary of the process options.

Table 4.47: Capital Cost for New Processes & Expansion of Existing Ones

Main Process Unit	Capacity t/y	1999 Costs $ million	Location Factor	1999 Local Cost $ million	2002(*) Local Cost $ million	Hydrogen balance unit, % of total cost
Debottlenecking/upgrading of existing Hydro-treating Capacity (**)	120,000	0.8	1.4	1.1	1.3	0%
Expansion of Existing catalytic Hydro-treating Capacity (***)	250,000	10.1	1.4	14.1	16.4	8%
Isomerization	100,000	8.1	1.4	11.3	13.1	5%
(chlorided alumina based)	150,000	10.3	1.4	14.4	16.6	5%
High Pressure (70 bar) Hydro-treating Unit	1,000,000	56.0	1.4	78.4	90.8	10%
Complete Hydro-cracker unit (Vacuum dist., hydro	1,000,000	98.0	1.4	137.2	158.8	14%
treating, hydro-cracking)	1,500,000	125.0	1.4	175.0	202.6	14%
Expansion of Reformer:						
To process Hydro-cracker naphtha (type 3 cases)	140,000	19.2	1.4	26.9	31.1	0%
As part of Refinery Capacity Expansion (type 5 cases)	260,000	27.8	1.4	38.9	45.1	0%
Combination of above (type 4 cases) (*)	440,000	38.1	1.4	53.3	61.7	0%
Expansion of Existing CDU Capacity (****)	2,200,000	52.0	1.4	72.8	84.3	0%

(*) The 2002 costs were calculated from the 1999 ones by increasing them at a rate of 5% per annum.
(**) current capacity of 350 t/cd (see Table 6.3.1)
(***) additional to current capacity
(****) taking into account the refinery capacity expansion and the higher hydro-cracker capacity of type 4 cases versus type 3 cases

The capacity of the reformer for the various cases has been assumed as follows:

- Cases type 1 and 2: no change versus base
- Cases type 3: expansion of 140,000 t/y in order to process all the naphtha produced by the hydro-cracker
- Sensitivity Cases type 5 (described in Appendix 6): expansion of 260,000 t/y, consistent with doubling of the capacity of the refinery. This level of expansion has been selected in order to produce enough unleaded gasoline at 90 RON to satisfy the market demand for the period 2010 to 2015.
- Sensitivity Cases type 4 (described in Appendix 6): expansion of 440,000 t/y, which is the sum of the above 260,000t/y, plus additional capacity to be able to process all the naphtha calculated to be produced by the hydro-cracker capacity assumed for these cases.
- The hydrogen balance units are hydrogen generation plants that are necessary to provide the amount of hydrogen required by each process and not entirely available from normal refinery processes such as the reforming unit. The cost of these hydrogen plants is usually expressed as a percent of the cost of the unit they feed. The information in this table can be useful to assess the contribution of each process to the total level of investment of each case study.

The marginal operating costs, relative to running new or expanded existing process units, have been estimated to be 5% of the annualised capital cost, consistently with normal practice in these types of refinery upgrading and expansion projects. Regarding gasoline blending components and the use of larger fractions of low sulphur crudes in the refinery crude slate, the model uses the current Singapore market prices as follows (posted prices on the 23rd of April 2002, which are representative of recent price increases):

- MTBE: 330 $/t
- MMT: 25,000 $/t
- 95 RON Unleaded Gasoline: 30.40 $/barrel
- 92 RON Unleaded Gasoline: 29.35 $/barrel
- Naphtha: 26.35 $/barrel
- Reforumate: 30.1 $/barrel
- Additional cost of low sulphur MIRI crude versus other crudes in the slate: 1.7 $/barrel
- Gasoil 1% Sulphur : 28.10 $/barrel
- Gasoil 0.5% Sulphur (interpolated between 1% and 0.25%) : $28.40/barrel
- Gasoil 0.25% Sulphur : 28.60 $/barrel
- Gasoil 0.05% Sulphur : 29.10 $/barrel
- Crude Oil : 24.8 $/barrel
- Heavy Fuel Oil : 156 $/tonne
- freight cost from Singapore : 1.2 $/barrel

It is worth noting that, while the absolute prices of each grade change with market trends, the price differentials among the grades remain fairly constant.

Methodology for Cost Calculation

For each case, revenues and costs were calculated, vs base case, taking into account refinery production, exports and imports. On top of this, the impact of refining investments for new or upgraded units was calculated. In this way, the cost differences between the base case and the alternatives cases were computed. The base case for gasoline is case 1C of the study, and the case labelled "Base Case" on page 68 for diesel.

Regarding product prices, it is assumed that both the products manufactured in Sri Lanka and those imported are priced at the Singapore FOB values. For the imports, the freight cost is added. In this way the products imported carry a loss equivalent to the freight cost vs those manufactured locally.

Therefore, the results of these calculations must be interpreted in this light and evaluated with caution, especially in a market, like the Asian one, where there is a surplus of products (particularly diesel fuel and refining capacity). **This surplus situation is expected to exist in the region for quite some time. This buyers' market condition is important to be kept in mind when making decisions about further investments in the refinery sector.**

For each case the gasoline and diesel fuel demands were satisfied assuming to use the combination of locally manufactured blending components and imported blending stocks and finished products.
The market demands for the various study cases were assumed as follows:

	Year	Gasoline t/y	Auto Diesel Fuel t/y	Scanario
Cases Type 1 & 2	2005	280,000	2,100,000	2
Cases Type 3	2010	437,500	2,700,000	mid point between 1 & 2
Cases Type 4 & 5	2015	790,000	3,250,000	1

4.7.3 Discussion of Results

4.7.3.1 Upgrading of Existing Refinery - Step 1

The Step 1 of the refining upgrading represents a set of short term measures which include:

- de-bottlenecking and expansion of the existing gasoil hydro-treating facilities up to a capacity of 370,000 t/y. This includes restarting the already existing gasoil hydro-treating unit that has a capacity of 350 t/day (or about 120,000 t/y). It was assumed that this hydro-treating plant would be a medium pressure one (40 to 50 bar), able to produce gasoils with a sulphur content of 1000 ppm maximum. In upgrading both these units, in order to hydro-treat diesel fuel down to a sulpher level of 1000ppm max, a 25% reduction of the nominal installed capacity was assumed. (ie down to a round figure of 370,000t/y total).
- as this hydro-treated gasoil is blended with the remaining non-hydro-treated straight-run gasoil, some sensitivity cases were run assuming increasing amounts of low sulphur MIRI crude, from 20% (base case) to 30, 40 and 50%.
- gasoline blending: the gap of 3 RONs (between the unleaded gasoline produced by the refinery before moving to unleaded and the current specification of 90 minimum) was filled in four different ways, as summarised in the following table:

	No MMT	Use of MMT
Use of MTBE	X	X
Use of UL 95 RON	X	X

- as regards the use of MMT, it was assumed that the typical composition of the unleaded gasoline pool in Sri Lanka would need a treat rate of 0.018 gMn/lt (equivalent to a treat cost of 1.21 US$/t) to achieve a RON increase of 1 unit. This conservative approach was chosen given the low olefinic content of the gasoline of Sri Lanka, which may cause a relative low octane response to the addition of MMT. An experimental blending study, using local refinery steams, would be needed to optimise the MMT treat rate.
- the majority of diesel demand is met by imports. The study assumes that in the base case diesel containing 5,000 wt ppm sulphur is imported, while in the other cases the sulphur content is 2,500 wt ppm.

Gasoline was also blended by using only the two components presently available, but as it will be shown, this approach did not allow to meet the demand and the quality targets. The results of this calculation are reported under Case 1c, which is considered the study base case for gasoline.

The following two tables report a summary of the data, in terms of both product quality and volumes. Regarding the latter, the predicted volumes of gasoline and diesel fuel are compared to the 2005 short term forecast demands.

Gasoline production versus volume and quality targets:

	Case # 1a	Case # 1b	Case # 1c*	Case # 1d	Case # 1e	Case # 1f	Gasoline Demand	Target 2005
Blending Products:								
MTBE, t/y	33,300			28,100				
95 RON unleaded gasoline, t/y		58,500			49,450			
MMT				Yes	Yes	yes		
Production, t/y:								
Gasoline	280,000	280,000	210,250	280,000	280,000	218,600	**Scenario 1**	340,000
Reformate	0	0	0	0	0	0	**Scenario 2**	280,000
Naphtha	101,100	126,300	137,550	95,900	117,250	129,200		
Quality of gasoline produced:								
RON	90.0	90	90.0	90.0	90.0	90.0		90.0
MON	79.6	79.4	79.6	78.9	78.5	78.6		n.a.
Benzene, vol%	1.8	2.8	2.0	1.8	2.7	2.0		4.0
Aromatics, vol%	33.0	42.7	44.6	33.0	41.2	42.7		45
RVP, kPa	56	57	47	56	57	49		60

*Base case

Gasoline blending:

- In all cases the minimum RON specification of 90.0 was met.
  Regarding the projected demand for 2005, scenario 2 is the only realistic one, as meeting the target of scenario 1 would imply a very large switch from diesel to gasoline engine vehicles, that could not be realistically achieved by 2005.
- Case 1c (no use of imported high RON blending components) is clearly failing to meet the gasoline production targets for Scenario 2.
  Furthermore for this case, also the predicted Aromatics content is borderline versus the standard of 45% maximum. In this case, there is also the highest production of naphtha. Demand can only be met through imports of unleaded 90 RON gasoline (69,750 t/y- Case 1f is equivalent to Case 1c but with the assumption of using enough MMT to achieve a RON boost of 1 unit. Also in this case, the production is inadequate to meet the target demand and 61,440 t/y of unleaded 90 RON must be imported to meet demand.
- Cases 1a and 1d (use of MTBE without and with MMT respectively) are both meeting the gasoline market demand for Scenario 2 in 2005.
- Cases 1b and 1e (use of UL 95 RON without and with MMT respectively) are also both capable of meeting the gasoline market demand in 2005.

All the cases meet the fuel specifications for 2005 and 2010. Only the addition of MTBE enables compliance with the 2015 specifications.

	Case Base	Case # 1e	Case # 1g	Case # 1h	Case # 1i	Diesel Fuel Demand	Target 2005
Processes: Debottlenecking and expansion of the existing hydrotreating capacity	no	yes	yes	Yes	yes		
Use of Low S crude, % of slate	20	20	30	40	50		
Production, t/y:						**Scenario 1**	2,000,000
Diesel fuel	603,435	603,435	637,800	672,800	707,200	**Scenario 2**	2,100,000
Quality of diesel produced:							
Sulphur, wt ppm	9,084	3,901	3,437	3,023	2,625		3000
Cetane Index	45	48.0	47.0	46.0	45.0		46
T95, deg.C	380	382.2	382.2	382.2	382.2		380
Density, kg/litre	0.859	0.858	0.858	0.858	0.858		0.860
Poly Aromatics, wt%	11.4	11.4	11.4	11.4	11.4		12
Quality of imported diesel:							
Sulphur, wt ppm, max	5,000	2,500	2,500	2,500	2,500		

- The comparison of Case 1e with base case (current situation) shows the benefit of debottlenecking and expanding to 370,000 t/y the medium pressure hydro-treating capacity.
- Cases 1g, 1h, 1i show that processing more low sulphur MIRI crude gives an additional reduction of the sulphur content of the fuel, but has the adverse effect of reducing the cetane quality quite dramatically.
- The T95 specification requires some attention. In case 4 it is addressed through changing the cut point of the distillation unit and the addition of severe hydrogenation processes. With today's refinery configuration, the diesel cut point was kept fairly high to maximise diesel fuel production and avoid pushing some gasoil into the furnace oil. In the short range, an approach which would reduce T95, without sacrificing diesel production, could be the blending of some kerosene into the diesel fuel pool.In these calculations, no attempt was made to accurately predict detailed potential incremental capacity effects due to changing crude slate, as this was considered beyond the detail of the analysis of this study. However, the crude assay data was used to calculate the likely increase of diesel fuel production consequent to processing the lower sulphur MIRI crude. In fact this crude has higher distillate yields than the average crude slate of the base case.
- As very well known, the diesel fuel demand is much higher than the Sri Lankan refinery capacity. In case 4, the refinery capability of approaching market demand will be explored through an expansion plan coupled to the installation of a fairly large hydro-cracking capacity.

Overall, in the short range, the best course of action for the diesel fuel would be to expand the existing medium pressure hydro-treating plant, without which the sulphur content would be unacceptably high.

Cost implications. The following table shows the cost implications of all cases discussed in this section of the report.

	Case 1a	Case 1b	Case 1c	Case 1d	Case 1e	Case 1f	Case 1g	Case 1h	Case 1i
2002 Costs, US$ million									
Capital investments	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8
Annual operating costs:									
- due to the new units	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
- due to blending components, low S crude, imports/exports	5.76	4.07	3.67	5.88	4.46	4.02	4.94	5.38	5.86
Additional Product cost, Rs/lt:									
- gasoline	0.52	0.10	0.0	0.55	0.20	0.09	0.20	0.20	0.20
- diesel fuel	0.26	0.26	0.26	0.26	0.26	0.26	0.28	0.30	0.31

- The capital investment cost is entirely due to the de-bottlenecking and expansion of the gasoil hydro-treating facilities of the refinery.
- It is obvious that the use of MTBE is increasing the operating costs of the blending (Cases 1a and 1d). The same does the use of UL 95 RON as a high octane number blending component, albeit at a slightly lower rate..
- The use of more low sulphur crude in the slate is also increasing the operating costs (see the difference in operating costs due to blending components or low S crude between case 1e and cases 1g, 1h, 1i).
- The cost of using MMT (see case1f where MMT is used on its own) is quite low, which makes MMT a very cost-effective octane booster.

- About Rs 0.13-0.14 the incremental cost per litre of diesel is due to importing 2,500 wt ppm rather than 5,000 wt ppm sulphur fuel.
- The additional product costs for each case, expressed in Rupies per litre, are calculated on the following assumptions:
  a) spreading the capital investment cost over a time period of 10 years
  b) assuming an exchange rate of 93 Rs./US$ (i.e. today's exchange rate)
  c) the operating costs are allocated to either gasoline or diesel fuel as appropriate.

4.7.3.2 Upgrading of Existing Refinery - Step 2

The Step 2 of the refining upgrading includes the same short term measures of Step 1, with the addition of an isomerization plant with a capacity of 100,000 t/y. It was assumed that the isomerization unit uses a chlorided alumina based catalyst and has no effluent recycle. With these assumptions, the typical RON of the isomerate produced is about 83.This addition will give the refinery the capability to:

1) meet future gasoline demands
2) satisfy the future stricter gasoline specifications, particularly for aromatics, with more flexibility and hence more effectively

Gasoline blending:

The following table shows the effect on gasoline volumes and quality of using the isomerization naphtha (100,000 t/y capacity) together with the other measures described in Step 1. - The results show:

	Case # 2a	Case # 2b	Case # 2c	Case # 2d	Case # 2e	Case # 2f	Gasoline Demand	Target 2005
Blending Products:								
MTBE, t/y	5,000			2,000				
95 RON unleaded gasoline, t/y		25,500			3,450			
MMT				Yes	Yes	yes		
Production, t/y:								
Gasoline	280,000	280,000	276,000	280,000	280,000	280,000	**Scenario 1**	340,000
Reformate	9,200	26,600	1,100	13,200	13,100	9,500	**Scenario 2**	280,000
Naphtha	43,300	46,400	50,400	36,300	37,800	38,000		
Quality of gasoline produced:								
RON	90.0	90.0	90.0	90.0	90.0	90.0		90.0
MON	80.0	79.9	80.3	79.3	79.4	79.3		n.a.
Benzene, vol%	1.2	1.6	1.3	1.2	1.3	1.3		4.0
Aromatics, vol%	31.1	32.0	33.1	30.3	30.9	31.2		45
RVP, kPa	57	59	57	57	58	58		60

- The isomerization plant gives the following advantages versus Step 1 (Cases 1a to 1i):
  a) more naphtha can be used for gasoline blending, either directly as a gasoline component or indirectly by using it as feed for the isomerization plant.
  b) a consequence of this is that the gasoline demand is met in all cases (only in case 2c, 4,000 t/y of unleaded 90 RON must be imported),using less high octane blending components
  c) both the benzene and the total aromatics contents would be greatly reduced, easily meeting the study targets for 2015.
  d) the MON of the finished gasolines would be between 0.5 and 1.0 units higher, giving a better assurance of a knock-free operation of the gasoline vehicle population.

The addition of an isomerization unit to Step 1 would have no impact on the volumes and quality of diesel fuel produced.

The investment and operation costs of Step 2 are reported in the following table:

	Case 2a	Case 2b	Case 2c	Case 2d	Case 2e	Case 2f
2002 Costs, US$ million						
Capital investments	39.3	39.3	39.3	39.3	39.3	39.3
Annual operating costs:						
- due to the new units	0.26	0.26	0.26	0.26	0.26	0.26
- due to blending components, Imports and exports	3.14	3.29	2.75	3.47	3.37	3.28
Additional Product cost, Rs/lt:						
- gasoline	0.45	0.48	0.35	0.53	0.50	0.48
- diesel fuel	0.26	0.26	0.26	0.26	0.26	0.26

Compared to Step 1, the capital investment costs increase by about US $ 16.5 M to about US $ 39 M, but the variable operating cost relative to the use of high octane blending components are significantly reduced, as the octane quality now comes from having upgraded the virgin naphtha to isomerate. Overall, the additional cost of the transport fuel is only marginally increased as the effects of higher investments and lower operating costs tend to partially compensate each other. The use of MTBE or MMT give no advantage over case 2c for the purpose of meeting fuel quality targets while incurring a significant extra cost. While later on in the study we see that MTBE reduces CO and HC emissions, ambient CO and ozone concentrations are low in Colombo at the moment, with only PM10 being a problem.

4.7.3.3 Upgrading of Existing Refinery - Step 3

In Section 4.7.3.2, it was mentioned that Step 2 made no additional impact on the production and quality of the diesel fuel. Step 3 is now addressing the issue by adding a hydro-cracker unit to the processes and blending components available in Step 2. To better understand these results, the following explanations are needed:

- in all Cases from 3a to 3h included, the study assumed a hydro-cracker capacity of 850,000 t/y, that is the capacity necessary to hydro-crack the vacuum gasoil produced by the vacuum distillation of all the available heavy fuel oil plus the visbreaker gasoil.
- in the Cases from 3i to 3l, the hydro-cracker capacity was gradually increased in order to hydro-crack also growing amounts of straight-run gasoil, with the aim of producing diesel fuels of very good quality, consistent with EURO II/III and the World-wide fuel Charter Category 2.
- it was assumed that the hydro-cracker naphtha (with an RON of about 80) is used as additional reformer feed (as done by most modern refineries to increase its RON to about 93/95), instead of using it directly as a blending component. In this way, the gasoline production has been substantially increased as well, and the reformer had to be de-bottlenecked and expanded accordingly.

- an isomerization plant with a capacity of 100,000 t/y in included in Cases 3a and 3b, but it has been excluded from Cases 3c to 3l, in order to separate the effects of the hydro-cracker and the isomerization units.
- in all cases, the sulphur content of the imported diesel is 500 wt ppm against the base case of 5,000 wt ppm.
- it is worth noting that, with the installation of a hydro-cracker, the refinery would not produce any furnace oil anymore; the marked demand for this product would have to be entirely satisfied through imports.
- as the hydro-cracker unit produces both more diesel fuel and gasoline, for step 3, the product cost implications will not be calculated for gasoline and diesel fuel individually, but for the sum of these two transportation fuels.

The gasoline blending implications of Step 3 are shown in the following table:

	Case # 3a	Case # 3b	Case # 3c	Case # 3e	Case # 3f	Case # 3g	Case # 3h
Blending Products:							
MTBE, t/y				30,900	23,000		
95 RON unleaded gasoline, t/y						40,500	54,400
MMT	No	yes	no	no	yes	yes	no
Isomerization Plant	Yes	yes	No	No	no	no	no
Production, t/y:							
Gasoline	437,500	347,500	372,600	437,500	437,500	437,500	437,500
Reformate	4,300	19,000	0	0	0	0	0
Naphtha	27,100	12,400	98,300	82,600	74,700	92,100	106,100
Quality of gasoline produced:							
RON	90.0	90.0	90.0	90.0	90.0	90.0	90.0
MON	80.5	80.3	79.5	79.8	78.6	78.5	78.6
Benzene, vol%	1.5	1.5	2.0	1.9	1.9	2.4	2.5
Aromatics, vol%	37.0	35.2	44.6	37.6	37.6	41.9	43.5
RVP, kPa	56	56	56	54	56	58	57

- Cases 3a and 3b (with isomerization plant) look on average as the most attractive from the product quality point of view (higher MON and lower benzene and aromatics). Furthermore, these two cases do not require the importation of expensive MTBE or UL 95 RON
- The next set of cases (from 3c to 3h) describe the impact of the hydro-cracker plant without the isomerization one, on the volume and quality of gasoline produced.
- Case 3c: the gasoline was blended using only reformate and naphtha, achieving the minimum RON value of 90 but failing to meet the target demand for 2010. This approach would be border line in terms of aromatics content
- Case 3e: the gasoline demand was met using all the reformate, as much naphtha as possible and some MTBE . The product blended in this fashion met all product quality targets.
- Cases 3f and 3g are equivalent to cases 3e and 3h respectively, but with the additional assumption of using MMT in the blend. As MMT can provide the lift of one octane unit, the quantities of MTBE and UL 95 RON needed to meet the 90 RON minimum in the final blend are smaller when MMT is used, as equivalent volumes of finished gasoline are produced.
- In all cases, naphtha has been used as much as possible for the production of gasoline.
- The two cases involving blending of 95 RON unleaded gasoline, 3g and 3h, fail to meet the 2015 gasoline specification target.

The diesel fuel blending implications of Step 3 are shown in the following table:

	Case # 3a - 3h	Case # 3i	Case # 3j	Case # 3k	Case # 3l	Diesel Fuel Demand	Target 2005	Target 2010	Target 2015
Processes:									
Debottlenecking and expansion Of the existing Hydrotreating capacity	Yes	yes	yes	yes	yes				
Hydrocracker (capacity from 850,000 To 1,100,000 t/y)	Yes	yes	yes	yes	yes				
Straight-run gasoil sent to the Hydrocracker (on top of the vacuum & VB gasoils), t/y	0	50,000	100,000	150,000	200,000				
Production, t/y:						**Scenario 1**	2,000,000	2,600,000	3,250,000
Diesel Fuel	851,000	849,900	849,200	848,000	846,900	**Scenario 2**	2,100,000	2,800,000	3,600,000
Quality of diesel produced:									
Sulphur, wt ppm	413	356	298	240	182		3000	1000	500
Cetane Index	54.3	54.9	55.4	55.9	56.5		46	46	50
T95, deg.C	362.2	360.4	358.6	356.8	355.2		380	380	365
Density, kg/litre	0.846	0.845	0.844	0.843	0.843		0.860	0.860	0.860
Poly Aromatics, wt%	4.6	3.9	3.3	2.7	2.1		12	12	5

- In all cases, the sulphur content of the diesel imported is 500 wt ppm, against the base case of 5,000 wt ppm.
- In all cases the 2015 product quality targets are met with lot of margin, particularly regarding the cetane index and the sulphur content.
- The only parameter for which the target is only marginally met is the T95.- As expected, with the addition of a hydro-cracker, the diesel fuel production has increased, but it is still far from meeting the market demand.

It is obvious that, in a market dominated by the use of diesel fuel, the hydro-cracker represents a very important investment from the points of view of both the volume of product manufactured and its quality.

The cost implications of Step 3 are shown in the following table:

	Case 3a	Case 3b	Case 3c	Case 3e	Case 3f	Case 3g	Case 3h
2002 Costs, US$ million							
Capital investments	273.7	273.7	257.2	257.2	257.2	257.2	257.2
Annual operating costs:							
- due to the new units	1.82	1.82	1.71	1.71	1.71	1.71	1.71
- due to blending components, Imports and exports	38.65	39.61	39.58	41.51	41.73	40.57	39.95
Additional Product cost, Rs/lt:							
- transportation fuels (gasoline plus diesel fuel)	2.04	2.07	2.01	2.06	2.06	2.03	2.02

	Case 3i	Case 3j	Case 3k	Case 3l
2002 Costs, US$ million				
Capital investments	264.1	270.8	277.4	283.8
Annual operating costs:				
- due to the new units	1.76	1.80	1.85	1.89
- due to blending components or low S crude	40.20	40.36	40.62	40.87
Additional Product cost, Rs/lt:				
- transportation fuels (gasoline plus diesel fuel)	2.05	2.07	2.10	2.13

- With the addition of a full hydro-cracker plant (from additional vacuum distillation unity to an hydrogen plant) the capital investment has increased quite dramatically (from about US$39 M to US$ 260 to 290 M). However through this investment the refinery would have the following significant advantages:
  a) enough conversion capacity to upgrade all furnace oil to gasoline and diesel fuel
  b) flexibility to meet fairly advanced specifications for both gasoline and diesel fuel
  c) a modern structure that would guarantee, even with the present overall capacity, a continued viability for the next 15 to 20 years.
  d) against these significant benefits, this investment would increase the average cost of transport fuels (gasoline plus diesel fuel) by slightly more than 2 Rs. per litre, depending on the conditions of the various sub-cases which have been considered in this study.

Since the terms of reference of this study had been issued, this fuel supply scenario for the Sri Lancan market has evolved towards relying more on the importation of higher quality diesel fuel to satisfy future demand. Therefore the original interest for studying the eventuality of a refinery expansion has declined.

4.7.3.4 Observations

The data discussed in this chapter indicate the following possible course of action for the Sri Lankan refinery

- Short range (up to 2005)

a) use the currently available blending components and import enough 90 RON gasoline to satisfy market demand.
b) debottleneck and expand up to a capacity of 1000 t/day the gasoil hydrotreating unit
c) use more low sulphur crude in the crude slate if necessary

With these relatively low cost measures, the 2005 product quality targets will be met.

- Longer Range (up to 2015)

Assuming that the existing refinery capacity will be maintained, the following should be implemented in order to upgrade the fuel quality to the level of the 2015 targets for this study

a) build a new isomerization unit (with a capacity of 100,000 t/y for the current refinery capacity) to meet the 2015 gasoline specifications. Alternatively, the 2015 specifications can be met by using MTBE.
b) build a new complete hydrocracker (with a capacity of 1,000,000 t/y for the current refinery capacity) to meet the 2015 diesel specifications for polyaromatics and sulphur.

These investments will make the refinery viable for at least the next twenty years and will provide the flexibility necessary to satisfy the 2015 product quality targets of this study.

4.8. IMPACT OF FUEL CHANGES ON EXHAUST AND EVAPORATIVE EMISSIONS

In this section the impact on emissions of the fuel quality changes discussed in section 4.7 will be examined in detail. Both the exhaust and the evaporative emissions from gasoline engines and the exhaust emissions from diesel engines will be calculated.

For each of the following pollutants:
- Total Hydrocarbons (HC)
- Benzene
- Carbon Monoxide (CO)
- Nitrogen Oxides (NOx)
- Sulphur Oxides (SOx)
- Particulate Matter (PM10)
- Lead

The emission reductions achieved with selected fuel reformulations of Section 4.7 will be assessed against the current base case qualities for both gasoline and diesel fuel.

4.8.1 Methodology

The emissions are calculated using an emission inventory model. This model, originally developed for IPIECA (International Petroleum Industry Environmental Conservation Association) by Enstrat International Ltd., has the flexibility to be locally customised and accepts local vehicle populations, vehicle field use data inputs (annual mileage, average traffic speeds, local emission factors when they exist, etc.), typical local fuel qualities.

Vehicle population data from 1974 to 2000 was provided for this study by the Ministry of Transport of Sri Lanka for the following vehicle categories:

	Gasoline Engined Vehicles	Diesel Engined Vehicles
Cars and light vehicles	X	x
Taxis	x	
Pick-up & Dual Purpose	x	x
Minibuses	x	x
Medium Buses		X
Heavy Buses		X
4-wheel-drive		X
Trucks	x	X
Land vehicles		x
Motor-cycles	x	
Motor-tricycles	x	

This vehicle population data was used to prepare a Sri Lankan customised version of the emission inventory model. As some of the fuel specification changes discussed in Chapter 3 were not assumed to take place before 2010 or 2015, the above car population input was extrapolated beyond 2000 up to 2015, using the following approach:

- step 1: assume that the vehicle growth for each category would continue with the same trend of the period 1990/2000.
- step 2: check against the fuel demands calculated for the same period 2000/2015 and ensure consistency.

No data was made available for this study on typical Sri Lankan average annual mileage, average speeds and type of driving by vehicle type. In this situation, an analysis was made of input data used for studies carried out in neighbouring countries (e.g. India and Bangladesh); this information formed the basis for these data inputs into the model version prepared for Sri Lanka.

As regards the emission factors to be used in the model, they were selected to represent Japanese and European vehicles without advanced emission control technologies and without the existence of mandatory Inspection and Maintenance programmes. The only exception is the tricycles, for which the model used emission factors adopted for similar vehicles in studies in India and Bangladesh.

For the study and the calculation of the impact on emissions of changing the gasoline and diesel fuel quality, the model is using complex equations that relate variations in individual fuel parameters to emissions. These equations are based on the following research programmes:
- Gasoline changes: US AQIRP and European Union EPEFE studies
- Diesel fuel changes: European Union EPEFE study.

4.8.2 Selection of Reformulated Fuels to be tested against the Base Case

From an analysis of Section 4.7, the following fuels were selected for the calculation of their emission reduction versus the base case fuel specification:
- gasolines from Cases: 1a, 1b, 2a
- diesel fuels from Cases: 1e, 1h, 3h, 3l, 4g, 5k

The fuel qualities from the above cases cover the range of product qualities calculated by the refinery study, as described in Chapter 3. The essential features of these selected fuels are shown again in the following tables, together with the base fuel charactiristics:

	Gasoline 1a	Gasoline 1b	Gasoline 2a	Gasoline Base
RON	90.0	90.0	90.0	90.0
MON	79.3	79.2	80.1	79.6
Benzene, vol%	1.8	2.8	1.2	2.0
Aromatics, vol%	33.0	42.7	31.3	44.6
RVP, kPa	54	57	58	47
Oxygen, wt%	2.2	0.0	0.3	0.0

	Diesel 1e	Diesel 1h	Diesel 3h	Diesel 3l	Diesel 4g	Diesel 5k	Diesel Base
Sulphur, ppm	3,901	3,023	413	182	2,650	452	9,084
Cetane Index	48.0	48.0	54.3	56.5	51.6	49.5	45.0
T95, deg.C	382.2	382.2	362.2	355.2	371.3	377.6	380.0
Density, kg/litre	0.858	0.858	0.846	0.843	0.851	0.854	0.859
Poly Aromatics, wt%	11.4	11.4	4.6	2.1	7.9	10.5	11.4

The processes used to manufacture and blend these fuels, and their corresponding manufacturing costs, were extensively discussed in 4.7. These reformulated gasolines and diesel fuels were assessed, in terms of their emission reduction potential, in the following combinations:

Table 4.48: Combination of Reformulated Gasolines and Diesel Fuels

	Gasoline	Diesel Fuel
Reformulated Fuels 1	1a	Base
Reformulated Fuels 2	1b	Base
Reformulated Fuels 3	2a	Base
Reformulated Fuels 4	1a	1e
Reformulated Fuels 5	1a	1h
Reformulated Fuels 6	2a	3h
Reformulated Fuels 7	2a	3l
Reformulated Fuels 8	Base	3l
Reformulated Fuels 9	2a	4g
Reformulated Fuels 10	2a	5k

In this way, the effects of the gasoline and the diesel fuel can be separated, and their individual impacts on the emissions of the various pollutants can be observed.

4.8.3 Base Case: Prediction of Fuel Use

Before calculating the impact of the above reformulated fuels, the Emission Inventory Model was asked to calculate the amount of transport fuel used by the vehicle fleets and their pollutant emissions in the base case conditions. The calculation of the annual fuel consumption of the fleet has the main purpose of validating the assumptions in terms of average annual mileage, average speeds, type of driving for each vehicle category. This validation is made against actual market fuel demand data available from past years. For a good validation, the experience of having run many similar programmes requires that the difference between actual market data and Model predicted data be lower than 10%. As mentioned before, no data was available locally on consistent sets of annual mileage and average speeds for all types of vehicles. Therefore, the assumptions about these parameters for gasoline vehicles were changed until the fuel consumption predicted by the model and the actual market demand for the year 2000 were within 10%. This approach contributes to improving the reliability of the emission prediction of the emission inventory model. The results are shown in the following table:

Table 4.49: Transport Fuel Demand -Inventory Model Predicted Vs. Actual (Scenario 1) (Year 2000, t/y)

	Actual	Model Predicted	% Difference
Gasoline	225,000	245,000	8.9%
Diesel Fuel	1,316,000	1,362,000	3.50%

The model prediction of a higher gasoline market demand (about 9%) is likely to be due to the high incidence on total demand of the fuel used by the tri-cycles, for which there are very few published data on fuel consumption. This lack of good quality data can explain the difference. The prediction of the diesel fuel demand is 3.5% higher than the actual consumption in 2000.

Given the uncertainty in the modes of operation of the various segments of the total vehicle population, these discrepancies can be accepted, and give us the assurance that also the emission predictions could have the same level of accuracy, if the emission factors adopted for the model are representative enough of the emission performance of the vehicles of Sri Lanka.

4.8.4 Base Case: Exhaust Emissions

The base case emissions, i.e. the "do nothing scenario" were calculated for the period between 1990 and 2015 for each of the pollutants listed at the beginning of this Chapter. The results are reviewed for the individual pollutants. This review is important for understanding the emission reduction impact of the reformulated fuels. The fuel impact is highly dependent on the vehicle fleet composition and the relative contribution that each segment of the fleet makes to the total emissions.

Lead Emissions
With the assumption that lead additives will not be blended any longer into gasoline from the second half of 2002, the lead emissions would reduce as follows:

Table 4.50: Total Lead Emissions from transport, t/y

	Annual Emissions t/y
1990	61.8
1995	67.3
2000	79.0
2005	6.3
2010	1.3
2015	1.0

The residual amount of lead still emitted after 2003 is due to an assumed level of contamination in the fuel distribution system that is consistent with world-wide experience. This contamination will be particularly relevant in the case of Sri Lanka, due to the large levels of total fuel imports. However, the levels of contamination assumed in this part of the study are consistent with legislation world-wide and with specifications like the Fuel Charter, which have the aim of protecting vehicle emission control technologies when they are introduced in a market. The assumed profile of contamination is:

- 0.013 g/lt from 2003 to 2006 included
- 0.006 g/lt from 2007 to 2009 included
- 0.003 g/lt from 2010 onwards

Carbon Monoxide (CO) Emissions

The following table shows the total CO emissions for the entire vehicle fleet of Sri Lanka and the relative contribution to these total emissions of the gasoline and diesel engine equipped vehicles:

Table 4.51: Carbon Monoxide Emissions, kt/y

	Grand Total kt/y	Gasoline engines %	Diesel engines %
1990	81.6	86%	14%
1995	108.0	86%	14%
2000	163.1	87%	13%
2005	241.3	89%	11%
2010	339.6	90%	10%
2015	456.2	91%	9%

The emission inventory model predictions show that:

- CO emissions have doubled between 1990 and 2000, and by 2015 are expected to grow by a factor of 5 to 6 versus 1990.
- as in the vast majority of cases, the larger amount of CO is emitted by gasoline engine vehicles.

As the gasoline engines are the bigger emitters of this pollutant, the CO emissions of these engines have been further broken down as follows:

Table 4.52: Carbon Monoxide Emissions by Type of Gasoline Vehicles % of Emissions of Gasoline Engine vehicles

	Passenger Cars < 7 Seat	Pick-up & Dual Purpose	Minibus	Motor-Cycles	Motor-Tricycles	Total Gasoline
Year 2000	15.2%	0.7%	0.3%	47.1%	34.8%	100.0%

The motorcycles and the motor-tricycles together contribute to more than 80% of the CO emissions of the gasoline engine vehicles.

Total Hydrocarbon (HC) Emissions
The following table shows the total HC emissions for entire vehicle fleet of Sri Lanka and the relative contribution to these total emissions of the gasoline and diesel engine equipped vehicles:

Table 4.53: Total Hydrocarbon Emissions, kt/y

	Grand Total kt/y	Gasoline engines %	Diesel engines %
1990	26.3	80%	20%
1995	38.0	82%	18%
2000	62.4	86%	14%
2005	95.2	89%	11%
2010	135.7	90%	10%
2015	182.8	91%	9%

The emission inventory model predictions show that:
- HC emissions have more than doubled between 1990 and 2000, and by 2015 are expected to grow by a factor of 6 to 7 versus 1990.
- as in the vast majority of cases, the larger amount of HC is emitted by gasoline engine vehicles.
- these emission values include both the exhaust and the evaporative emissions

As the gasoline engines are the bigger emitters of this pollutant, the HC emissions of these engines have been further broken down as follows:

Table 4.54: Total Hydrocarbon Emissions by Type of Gasoline Vehicles % of Emissions of Gasoline Engine vehicles

	Passenger Cars < 7 Seat	Pick-up & Dual Purpose	Minibus	Motor-Cycles	Motor-Tricycles	Total Gasoline
Year 2000	8.8%	0.5%	0.2%	49.2%	40.6%	100.0%

The motor-cycles and the motor-tricycles together contribute to about 90% of the HC emissions of the gasoline engine vehicles. This is a conservative estimation, which may not take fully into account the existence of very high emitters in these two categories of vehicles, due to the practice of using large amounts of poor quality lubricating oils in the gasoline/engine oil mix.

Benzene Emissions
The emission inventory model is capable of predicting the exhaust emissions of several species of hydrocarbons and oxygenated components. Within the scope of this project, it has been deemed appropriate to calculate the emissions of benzene, considering its toxicity.

The predicted benzene emissions for the period from 1990 to 2015 are reported in the following table:

Table 4.55: Benzene Emissions, kt/y

	Gasoline Engines Emissions	Diesel engines Emissions
1990	1.0	0.03
1995	1.6	0.04
2000	2.7	0.08
2005	4.1	0.12
2010	6.0	0.17
2015	8.1	0.24

The benzene emissions from diesel engines are almost insignificant compared to those from the gasoline engines. Therefore, in this study, from now on, only the benzene emissions from gasoline engines will be discussed. It is worth noting that these emissions more than doubled between 1990 and 2000, and are predicted to increase by a factor of 8 between 1990 and 2015.

Nitrogen Oxides (NOx) Emissions
The following table shows the total NOx emissions for the entire vehicle fleet of Sri Lanka and the relative contribution to these total emissions of the gasoline and diesel engine equipped vehicles:

Table 4.56: Nitrogen Oxides Emissions, kt/y

	Grand Total kt/y	Gasoline engines %	Diesel engines %
1990	30.0	8%	92%
1995	38.3	6%	94%
2000	50.7	6%	94%
2005	66.9	7%	93%
2010	84.0	8%	92%
2015	106.7	9%	91%

The emission inventory model predictions show that:

- NOx emissions have increased by 60% between 1990 and 2000, and, by 2015, are expected to grow by a factor of 3 versus 1990.
- as in almost all cases, the larger amount of NOx is emitted by diesel engine vehicles.

As the diesel engines are the bigger emitters of this pollutant, the NOx emissions of these engines have been further broken down as follows:

Table 4.57: Nitrogen Oxides Emissions by Type of Diesel Engine Vehicles % of Emissions of Diesel Engine vehicles

	Cars & Light Vehicles	Medium bus	Minibus	Pick-up & dual Purpose	4 WD	Heavy buses & Trucks (B)	Land vehicles	Total diesel
Year 2000	1.2%	3.5%	0.9%	8.0%	0.7%	68.1%	17.6%	100.0%

The heavy buses and trucks together contribute to almost 70% of the NOx emissions of the diesel engine vehicles.

Particulate Matter (PM10) Emissions
The following table shows the total PM10 emissions for the entire vehicle fleet of Sri Lanka and the relative contribution to these total emissions of the gasoline and diesel engine equipped vehicles:

Table 4.58: Particulate Matter Emissions, kt/y

	Grand Total kt/y	Gasoline engines %	Diesel engines %
1990	4.1	14%	86%
1995	5.7	16%	84%
2000	8.0	21%	79%
2005	10.8	25%	75%
2010	13.9	28%	72%
2015	17.8	29%	71%

However, some potentially large uncertanties exist about the ability of these data to represent the actual situation of Sri Lanka. In fact no published PM10 emission data exist from actual vehicles operated according to the typical maintenance conditions and with the average local diesel fuels prevailing in Sri Lanka. In particular, because of the high sulphur level of the fuel, assumptions had to be made on how to interpret the outputs of the emission inventory model, as sulphur levels around 9000 ppm were largely outside the range of fuels assessed when the model was built.

Therefore, in considering the findings of this section of the study, lot of caution should be used. With this in mind, the emission inventory model predictions show that:

- PM10 emissions have doubled between 1990 and 2000, and, by 2015, are expected to grow by a factor of at least four versus 1990.
- as in almost all cases, the larger amount of PM10 is emitted by diesel engine vehicles.
- the contribution of the gasoline engines is chiefly due to the fast growing fleets of motor-cycles and tri-cycles.

The total PM10 emissions from the diesel engines have been devided into sulphur based particulates and other types of particles, mainly made of carbonaceous materials. These data are shown in the following Table 8.4.9.1. The sulphur based particulate matter has been calculated through a mass balance, assuming the current typical base case sulphur level of the diesel fuel in Sri Lanka, i.e. 0.9%. In thi situation, the sulphur based particulates represent about 17% of the total emissions.

As the diesel engines are the bigger emitters of this pollutant, the PM10 emissions of these engines have been further broken down as follows:

Table 4.59: Particulate Matter Emissions by Type of Diesel Engine Vehicles % of Emissions of Diesel Engine vehicles

	Cars & light vehicles	Medium bus	Minibus	Pick-up & dual purpose	4 WD	Heavy buses & Trucks (B)	Land Vehicles	Total diesel
Year 2000	**2.3%**	**3.3%**	**2.3%**	**19.7%**	**1.7%**	**61.4%**	**9.3%**	**100.0%**

The heavy buses and trucks together contribute to more than 60% of the PM10 emissions of the diesel engine vehicles.

Sulphate (SOx) Emissions

Contrary to the emissions of other pollutants, which are both engine design dependent and fuel quality dependent, the emissions of sulphates are directly linked to the sulphur content of the fuel. In the case of Sri Lanka, while the sulphur content of the diesel fuel is fairly high, the one of the gasoline is exceedingly low, as all the naphtha of the Sri Lankan refinery is hydro-treated. For this reason, more than 99% of the total sulphates are emitted by diesel engines. The data of the following table were calculated through a mass balance, based on the fuel sulphur content.

Table 4.60: Sulphates Emissions, kt/y

	Diesel Engines Emissions
1990	23.1
1995	31.4
2000	40.6
2005	52.0
2010	63.6
2015	79.3

The emissions of sulphates are growing proportionally to the growth of the diesel vehicle fleet.

4.8.5 Impact of Reformulated Fuels on Emissions

The impact on emissions of the combinations of gasoline and diesel fuels listed in Table 4.48 will be discussed in the following sections:

-4.8.5.1 Impact of reformulated gasoline only: Reformulated Fuels 1, 2, 3.
-4.8.5.2 Impact of reformulated diesel fuels: Reformulated Fuels 4, 5, 6, 7, 9, 10.

4.8.5.1 Impact of Reformulated Gasoline on Emissions

The first three reformulated fuel cases involve changes of the gasoline quality, while the diesel fuel quality is kept constant at the base case level. In order to compare like with like, in all cases the model was asked to simulate the market introduction of the reformulated fuels in 2005, and the vehicle populations relative to **Scenario 1** were considered.

CO Emissions

The gasoline quality parameter that is chiefly affecting CO emission is the oxygen content. Other minor effects are due to changes in volatility and gasoline composition, particularly the aromatics content.

- gasoline 1b, which does not contain oxygenated compounds gave only a marginal CO reduction (about 1%).
- the CO emission reductions of gasolines 1a and 2a (which contain MTBE as a blending component) are much higher: about 13% for gasoline 1a, and 7% for 2a.
- no gasoline reformulation can go near to compensate for the emission increase due to the growth in vehicle population.

This would only be achieved through the use of catalyst technologies for the new gasoline vehicles introduced into the Sri Lankan market. The move to unleaded gasoline will make this possible from 2003 onwards.

Hydrocarbon Emissions

The above comments about the CO emissions are also applicable to the emission of total hydrocarbons.

Benzene Emissions

Gasolines 1a and 2a are both reducing benzene emissions versus base case for the following three reasons (in priority order):

- they have lower benzene contents, which is the parameter having the biggest impact on benzene emissions
- they have lower aromatics contents. These are also affecting benzene emissions, albeit at a much smaller rate than the benzene content.
- they reduce the total hydrocarbon emissions, and hence cause a parallel reduction of the benzene emissions

It is obvious that there is a strong correlation between gasoline benzene and aromatics contents and benzene vehicle exhaust emissions. Gasolines 1a and 2a, through the use of isomerate and/or MTBE as blending components, contain lower

levels of both benzene and aromatics, and cause reductions of benzene emissions approaching 30%

Gasoline 1b, which is blended with imported 95 RON unleaded gasoline of the current quality, contains higher levels of benzene and aromatics, and is estimated to cause a small increase of the benzene emissions versus the base case conditions.

Also in the case of benzene (in spite of emission reduction effects larger than those likely to be achieved for CO and HC), fuel reformulation alone (without being complemented by the use of advanced vehicle emission control technologies) is not sufficient to compensate for the emission increase due to the vehicle population growth.

Nitrogen Oxides Emissions
The above gasoline reformulation cases have practically no effect on NOx emissions. In all programmes in which results have been published to-date, NOx was the pollutant least affected by fuel reformulation.

The small emission increases reported in the above tables are due mainly to the oxygen content of the reformulated fuels.

General observation: the small changes in emission % reduction between the years from 2005 to 2015 are due to changes in vehicle population mixes (different vehicle categories grow at different rates over the years), and to the fact that different types of engines react differently to changes in fuel quality.

4.8.5.2 Impact of Reformulated Diesel Fuels on Emissions

The next six reformulated fuel cases involve mainly changes of the diesel fuel quality, while the gasoline quality is kept either at the 1a or at the 2a case level. In order to compare like with like, in all cases the model was asked to simulate the market introduction of the reformulated fuels in 2005.

CO Emissions
The reformulated diesel fuels have a very small impact on CO emissions, over and above the effects of the gasolines 1a and 2a, that, as discussed in the previous section, give a CO emission reduction of about 10%. The almost negligible impact of diesel fuel reformulation on CO emissions is mainly due to the following reason:
- diesel engines are emitting low quantities of CO in the base case. In fact, as they operate with excess air, they are inherently low emitters of CO. The contribution of the diesel engines to the total CO emissions in the base case is less than 10 to15%.

Hydrocarbons Emissions
What said about the CO emissions also applies to the emissions of hydrocarbons from diesel engines.

Nitrogen Oxides Emissions

Diesel fuel reformulation has a small but significant impact on NOx emissions. Reductions from about 1% to up to 5% are predicted to be achievable. There is a clear correlation between the diesel fuel cetane quality and the emissions of NOx. It is worth noting that the three fuels with the highest cetane quality (and hence the lowest NOx emissions) are fuels 3h, 3l, 4g, that are all based on the use of hydro-cracked gasoil as a key blending component. Considering the importance of NOx in controlling the occurrence of ozone episodes, vehicle emission control technologies must be deployed, in parallel with diesel fuel reformulation, to balance the growth of NOx emissions with time, due to the growth of vehicle populations. Diesel engine technologies like EURO II, III can achieve, in urban driving, NOx emission reductions in the range of 50%, 65% respectively versus uncontrolled vehicles. These advanced diesel engine technologies require lower sulphur fuels, and therefore would be satisfied by the quality of the above reformulated diesel fuels. In the shorter range, while the refinery makes the necessary investments to reduce the sulphur content of the distillate manufactured locally, the new diesel vehicle technologies could be satisfied through the use of the imported Super Diesel.

Particulate Emissions

The same cautionary observations mentioned after Table 4.58 apply also to this section, as the same assumptions for calculating PM10 emissions were used. In particular, in the absence of local experimental emissions data, the emission factors used in the study may be significantly under-estimating the PM10 emissions in Sri Lanka, as they are taken from US and European data bases.

The reduction of PM10 emissions achievable through the deployment of the above six reformulated fuels is ranging from about 10% to 20%. It is obvious that reducing the sulphur content of the diesel fuel has a significant role in reducing particulate emissions. However other fuel parameters are important too. To quantify these relative effects, and to have some indications of the reduction of both carbonaceous material (soot) and sulphates, a separate programme was run on diesel fuel 3l, where the model was asked to assess the impact on PM10 emissions of each individual fuel quality parameter. The results are shown in the following Table 4.61.

Table 4.61: Impact on PM10 Emission of Individual Diesel Fuel Parameters

	Sulphur **Reduced from 9,000 to 171 ppm**	**CN** **Increased from 45 to 56.5**	**T95** **Reduced from 380 to 355.2°C**	**Density** **Reduced from 870 to 843 kg/litre**	**Poly-Aro** **Reduced from 11.4 to 2.1 wt%**	**Total**	**Total from Fuel 3l**
	Reduction, kt/y	Reduction, kt/y	Reduction,kt/y %	Reduction, kt/y	Reduction, kt/y	Reduction, kt/y	Reduction, kt/y
2005	0.98	-0.15	0.15	0.77	0.76	2.51	2.51
2010	1.16	-0.19	0.19	0.98	0.98	3.12	3.12
2015	1.40	-0.24	0.24	1.25	1.25	3.90	3.90
%							
2005	9.04%	-1.38%	1.35%	7.11%	7.05%	23.2%	23.2%
2010	8.32%	-1.35%	1.34%	7.03%	7.01%	22.3%	22.3%
2015	7.85%	-1.33%	1.33%	7.02%	7.02%	21.9%	21.9%

Comments:

- the reduction of sulphate emissions represents about one third of the total PM10 emission reduction.
- the reduction of carbonaceous material (which is linked to the incidence of lung cancer due to inhalation of particulate matter) is between 60% and 70% of the total PM reduction, and it is mainly influenced by the fuel density and its content of poly-aromatic hydrocarbon species. In other studies it has been found that carbonaceous PM emissions correlate with the total aromatics content of the diesel fuel. This is consistent with our findings, as total aromatics tend to correlate with density and poly-aromatics. However, it should be noted that carbonaceous components are a strong function of the condition of the vehicle (especially preventative maintenance) and operating conditions (such as over-loading and over-fueling), for which little data are available in Sri Lanka. Therefore, these estimates contain large uncertainties.
- also in this case, fuel reformulation must be complemented by the market introduction of advanced vehicle emission control technologies in order to compensate for the emisions growth caused by the increasing size of the vehicle fleets.

Sulphates Emissions

Fuel quality is the only variable affecting sulphate emissions from diesel engines. Therefore the emission reduction of sulphates is directly proportional to the reduction of the sulphur content of the diesel fuel. When the latter is reduced below 500 ppm, the sulphate emissions are reduced by more than 90/95% versus the base case. However it must be remembered that the air quality improvement will be lower in %, unless sulphate emissions from stationary sources (power generation, industry, commercial and domestic activities, etc.) are also reduced in the same proportion.

4.8.5.3 Vehicle Emission Control Technologies

The previous section 4.8.5.2 reviewed the direct role that gasoline and diesel fuel reformulation can have on vehicle emissions, in the context of the vehicle population of Sri Lanka. However improving fuel quality can also make possible the adoptions of more advanced vehicle emission control technologies, which can give, in conjunction with fuel reformulation, much larger emission reductions, particularly in the long range. Two typical examples, that will be explored in this section of the report, are:

- Use of catalysts, on light duty gasoline engine vehicles, in conjunction with unleaded gasoline
- Adoption of EURO II technologies, on diesel engine vehicles, in conjunction with low sulphur diesel fuel (with sulphur below 500 ppm)

4.8.5.3.1 Effect of Catalysts on Light Duty Gasoline Engine Vehicles

To quantify this effect, the Emission Inventory Model was asked to assume, as a study case, that, from January 2003, all new registrations of light duty gasoline vehicles be equipped with a "three-way"catalytic device (i.e. with a catalyst capable of reducing, at the same time, the emissions of carbon monoxide, hydrocarbons and nitrogen oxides). This catalyst technology has been assessed together with unleaded reformulated gasoline 2a. The results of this test are summarised in the following Table 4.62, where the estimated emissions relative to the use of gasoline 2a plus the catalyst are compared to those relative to the use of gasoline 2a alone.

Table 4.62: Emission Reductions -- Catalyst plus Gasoline Reformulation
(The Emission Reductions are calculated versus the base case, considering the entire vehicle population of Sri Lanka)

	Year	CO Reduct., kt/y	CO Reduct., %	HC Reduct., kt/y	HC Reduct., %	NOx Reduct., kt/y	NOx Reduct., %
Gasoline 2a	2005	27	11.0	6	6.1	-0.2	-0.4
	2010	38	11.2	8	6.4	-0.4	-0.4
	2015	52	11.3	12	6.5	-0.5	-0.5
Gasoline 2a Plus Catalyst	2005	36	15.0	7	7.1	5	1.7
	2010	57	16.6	12	8.6	10	3.5
	2015	82	18.0	18	10.1	16	5.2

To understand the emission control potential of the adoption of the catalyst in Sri Lanka, it is essential to consider again the emission profiles of the base case, discussed in Section 8.4 of this report. We need in fact to understand why the reduction of the emissions of the entire vehicle population of Sri Lanka is not larger, when the catalyst is adopted, and is not consistent with the experience in USA and Europe. The answer is clearly in the make-up of the Sri Lankan vehicle fleet, in fact:

- because of the large populations of motor-cycles and motor tri-cycles, versus the populations of the passenger cars and other light duty gasoline vehicles, the latter contribute in 2000 only about 15% of the total CO emissions and less than 10% of the total hydrocarbon emissions (see Tables 4.52 and 4.54 for more details)
- regarding the emissions of nitrogen oxides, they are greatly affected by the very large diesel vehicle populations of Sri Lanka, taking also into account the fact that the diesel engines are inherently high emitters of nitrogen oxides.

In summary, should larger emission reductions of CO, HC and NOx be needed (for air quality reasons) than those achievable with the use of the catalyst, other measures should be implemented, such as:

- Control of the CO and HC emissions from the two-stroke engine vehicles (motor cycles and tri-cycles)
- Control of the NOx emissions from the diesel engines, as discussed in the next case (section 4.8.5.3.2).

4.8.5.3.2 Effect of EURO II Engine Technology on Diesel Engine Vehicles

To quantify this effect, the Emission Inventory Model was asked to assume, as a study case, that, from January 2005, all new registrations of diesel vehicles be equipped with the EURO II engine technology for emission control.

This technology has been assessed together with the low sulphur diesel fuel 3h. The results of this test are summarised in the following Table 4.63, where the estimated emissions

relative to the use of diesel fuel 3h plus EURO II are compared to those relative to the use of diesel fuel 3h alone.

Table 4.63: Emission Reductions – EURO II Technologies plus Diesel Fuel Reformulation

(The Emission Reductions are calculated versus the base case, considering the entire vehicle population of Sri Lanka)

	Year	NOx Reduct., kt/y	NOx Reduct., %	PM10 Reduct., kt/y	PM10 Reduct., %
Diesel 3h	**2005**	3	4.6	2.1	19.2
	2010	4	4.5	2.6	18.5
	2015	5	4.4	3.2	18.1
Diesel 3h Plus	**2005**	16	24.5	3.9	36.3
EURO II	**2010**	39	46.4	5.8	41.6
Technology	**2015**	68	63.9	8.4	47.0

Because of the very large diesel engine vehicle populations of Sri Lanka, the adoption of the EURO II technology would cause very important reductions of the total emissions of nitrogen oxides and particulate matter. The combination of diesel fuel 3h and EURO II is estimated to reduce total NOx emissions by more than 60% and total PM10 emissions by almost 50% by 2015. The contribution of the EURO II vehicle technology alone to these emission reductions is estimated to be about 55 to 60% for NOx and about 30% for PM10.

The adoption of EURO II, with a diesel fuel quality of the type of fuel 3h, together with unleaded gasoline, the use of the catalyst and emission controls on motor cycles and motor tri-cycles would reverse the observed emission increase trend due to the significant growth of vehicle population in Sri Lanka.

4.9. CONCLUSIONS AND RECOMMENDATIONS

The transport fuel demand in Sri Lanka is characterised by a very low gasoline to distillate ratio. This defines the basis for process changes in order to cope with the elimination of lead from gasoline, improve the octane quality of the gasoline clear pool and tighten the overall diesel fuel specifications. Taking into account air quality considerations, the structure of the refining industry in Sri Lanka and the current trends in the neighbouring countries, it is proposed to tighten the transport fuel specifications as follows:

Table 4.64: Proposed Transport Fuel Quality - Study Targets

	Gasoline 2005	**Gasoline 2010**	**Gasoline 2015**	**Gasoline WWFC-Cat.2**
RON (gasoline pool), min	90 (*)	90 (*)	90 (*)	91
Lead, g/l max	0.013	0.008	0.005	below detection
Benzene, vol. %,max	4.0	3.0	2.0	2.5
Aromatics, vol. %,max	45	45	40	40
RVP, kPa,max	60	60	60	60
	Diesel Fuel 2005 (**)	**Diesel Fuel 2010**	**Diesel Fuel 2015**	**Diesel fuel WWFC-Cat.2**
Sulphur, wt. ppm,max	3000	1000	500	300
T95, deg.C,max	380	380	365	355
Density, kg/m3,max	860	860	860	820-950
Cetane index,min	46	46	50	50
Cetane number, min				53 (***)
Poly-aromatics, wt%	12	12	5	5

(*) The study assumed that the 95 RON unleaded grade will continue to be imported
(**) The study assumed that a Super Diesel grade will continue to be imported
(***) Compliance with either Cetane Index or Cetane Number is allowed.

The diesel fuel qualities proposed for 2015 are broadly similar to those postulated by EURO II/III and are approaching the World-wide Fuel Charter Diesel Category 2 quality. This study shows that, mainly because of the large diesel fuel demand in Sri Lanka, meeting these diesel fuel qualities will require large investments.

Gasoline Reformulation

Because of relatively low gasoline demand, the costs of lead elimination (already implemented in 2002) and octane upgrading are fairly low. In fact the gap of three RON units, between the octane quality before going unleaded (87 RON) and the target of 90 RON for the unleaded gasoline can be easily filled by the following approaches:

- short range: use the currently available blending components, and import enough 90 RON gasoline to meet market demand.
- long range: build an isomerization plant, which would have the advantages of reducing dependency on imports and increase the refinery flexibility to continue to meet future

gasoline demands at the proposed quality levels, not only regarding the octane quality, but also the benzene, aromatics (in particular) and volatility characteristics.

The costs of using these new blending components and investing in a new isomerization plant are:

- short range: none if the base case is selected. Incremental costsof up to 0.6 Rs. per litre of 90 RON unleaded gasoline encountered if MTBE, 95 RON unleaded and/or MMT are used.
- long range: a capital investment of about US$16.5M would be required for the isomerization plant, but the variable operating cost relative to the use of high octane blending components would be significantly reduced, as a large octane boost derives from having upgraded some of the naphtha to isomerate. Installing an isomerization unit to meet the gasoline specifications for 2015, incurs an additional cost of Rs. 0.35 per litre of 90 RON unleaded gasoline.

Diesel Fuel Reformulation

The diesel fuel presents the biggest challenge for two reasons:

- the market demand is unusually high, and clearly out of reach of the current refinery capacity. (For this reason, in this project, a sensitivity study was also examined aiming at improving diesel fuel quality at double refining capacity).
- the present sulphur content of the diesel fuel is high and needs important reductions

A large number of cases were considered in the study. The following five approaches represent a good summary of the case studies:

A) debottlenecking and expansion of current Low Pressure (LP) distillate hydro-treating unit. Current refining capacity.
B) as point A) plus the use of more low sulphur crude in the refinery crude slate.
C) as point A) plus a hydro-cracker unit.

Sensitivity Cases

D) as point C),i.e. with a hydro-cracker unit, but with a double refining capacity.
E) double refining capacity, but with the assumption of investing in a High Pressure (HP) hydro-treating unit instead of the hydro-cracker.

	Approach A)	Approach B)	Approach C)	Approach D)	Approach E)
Costs - 2002 US$ million:					
Capital Investments	22.8	22.8	283.8	545.3	322.6
Annual operating costs:					
- due to the new units	0.15	0.15	1.9	3.63	2.15
- due to blending components, low S crude, imports/exports	4.46	5.86	40.87	120.4	74.1
Additional Product cost, Rs/lt:					
- gasoline	0.20	0.20	n.a.	n.a.	n.a.
- diesel fuel	0.26	0.31	n.a.	n.a.	n.a.
-overall transportation fuels	n.a.	n.a.	2.13	3.87	2.28

n.a. - non applicable

The hydrocracker (approach C) is predicted to require large capital investments.

To double the refining capacity and build new modern refinery units (either hydro-crackers or HP hydro-treaters) would require very significant capital investments.

This product cost data must be interpeted in the light of the methodology used for their calculation. They must be assessed with caution, especially in a market, like the Asian one, where there is a surplus of product (particularly diesel fuel and refining capacity). This surplus situation is expected to persist in the region for quite some time. This buyers market condition is important to be kept in mind when making decisions about further investments in the refinery sector.

Each of the above approaches would improve the diesel fuel quality quite significantly. The sulphur and cetane quality levels are summarised in the next table:

	Approach A)	Approach B)	Approach C)	Approach D)	Approach E)
Sulphur content, wt ppm	3,900	2,625	413	383	301
Cetane index	48.0	45.0	54.3	53.7	49.6

Approach A) will satisfy the specifications foreseen for Sri Lanka in 2003, but it will fall short of meeting the specifications proposed in this study for 2005. These quality targets would be met by Approach B) regarding the sulphur content, but the cetane index value would be borderline, as the low sulphur crude used to reduce the sulphur content gives a low cetane quality.

The two hydro-cracker Approaches C) and D) meet all proposed specifications up to 2015. Approach E) clearly meets the 2005 and 2010 proposed quality targets, but is borderline regarding the 2015 proposed specifications. However the investment required by this approach is almost half of that required by Approach D).

Impact of Fuel Quality on Exhaust Emissions

A study was made of the impact of the effect that changing the fuel quality has on the emissions of the Sri Lankan vehicle fleet. This study was made using an emission inventory model, and it shows the following emission reductions for the gasoline and diesel fuel qualities of the levels proposed in Table 4.64 above.

Gasoline Reformulation:

- CO emissions from gasoline engines are largely affected by the use of oxygenated compounds as blending components. Therefore the fuel blends involving the use of MTBE as an octane booster would have the benefit of a 7% to13% emission reduction of CO. If imported 95 RON gasoline is used as a high octane blending component, the CO emissions remain practically unchanged.
- HC emissions follow the same trend of the CO emissions, albeit at a slightly lower percent level of emission reduction.
- Benzene emissions are those that are mostly affected by the above gasoline reformulations. The model predicted reductions are that almost 30% emission reductions

could be achieved when MTBE and isomerates are used as blending components.

The proposed gasoline reformulations have practically no impact on NOx emissions.

It is important to note that for all pollutants (including benzene which is the one mostly affected by gasoline quality changes) gasoline reformulation alone, without being complemented by the use of advanced vehicle emission control technologies, is not sufficient to compensate for the emission increases that took place in Sri Lanka in the last fifteen to twenty years due to the vehicle population growth. Only the deployment of catalysts on new gasoline engine vehicles entering the Sri Lankan market and the control of emissions from motor cycles and tri-cycles (gradually moving these fleets from two-stroke to four-stroke engines) can reverse this trend. With the move to unleaded gasoline in 2003, and because of the inherent low sulphur content of the gasoline manufactured in Sri Lanka, the catalysts would operate very effectively.

Diesel Fuel Reformulation:

- reformulated diesel fuel are chiefly affecting the emissions of NOx, PM10 and SOx.
- diesel fuels meeting the proposed 2005 specifications would reduce PM10 emissions by about 10% and SOx emissions by 70%, while their effect on NOx emissions would be negligible.
- the fuels satisfying the proposed 2010 specifications would reduce NOx emissions by about 2%, PM10 emissions by at least 15% and SOx emissions by about 85%.
- finally, the diesel fuel meeting the proposed 2015 limits would reduce NOx emissions by about 4%, PM10 emissions by 20 to 25% and SOx emissions by about 95%.

It is worth noting that:

- NOx emissions are only marginally affected by fuel reformulations
- SOx emissions depend only on the fuel composition; hence they are greatly affected by fuel reformulation.
- Substantial PM10 reductions seem to be possible through diesel fuel reformulation. However it is important to note that, because of the lack of published experimental data with diesel fuels of the quality marketed in Sri Lanka, the above estimates have been made through a set of assumptions, which were not fully tested by experimental programmes. Therefore these PM10 emission numbers contain potentially large uncertanties and must be interpreted with caution.

Also in this case, fuel reformulation alone, without being complemented by the use of advanced vehicle emission control technologies, is not sufficient to compensate for the NOx and PM10 emission increases that took place in Sri Lanka in the last 15 to 20 years due to the vehicle population growth. Only the deployment of emission control technologies such as EURO II and/or EURO III can invert this emission growing trend. A case study, which assumed the adoption of EURO II vehicle and diesel fuel technologies on new vehicle registrations from 2005, showed possible NOx and PM10 emission reductions up to 65% and 50% respectively by 2015.

After careful review of all the information developed on refinery investments, fuel quality improvements and their impact on emissions, the following is recommended for upgrading the refinery and improving its flexibility in satisfying tighter gasoline and diesel fuel specifications:

Unleaded Gasoline: - short range (up to 2005): use currently available blending components, and import enough 90 RON gasoline to satisfy market demand.
- longer range (2010--2015): invest in an isomerization plant to:
- upgrade the virgin naphtha from about 67/69 RON to 83 RON
- reduce dependency on expensive MTBE
- increase flexibility in meeting RON, Benzene/Aromatics specifications

Diesel fuels: - short range (up to 2005): maximise use of existing hydro-treating capacity and use more low sulphur crude aiming at achieving at least sulphur level of 2,500 to 3,000 ppm
- longer range (2010--2015): invest in a hydro-cracker to:
  a) produce more distillate and move the refinery production closer to market demand, and
  b) give the refinery the necessary flexibility for meeting lower sulphur and other future diesel fuel specifications (with this investment, fuel qualities like those postulated by EURO II/III and/or World-wide Fuel Charter - Diesel Category 2 will become feasible)

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Chapter - 5

FISCAL POLICIES ON FUELS AND VEHICLES

5.1 BACKGROUND AND OBJECTIVES

5.1.1 Background

The study on Fiscal Policies on Fuels and Vehicles in Sri Lanka was conducted within the overall framework of the Urban Air Quality Management Project. The overall objective of the project was to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions. The study was undertaken by the international consultant "Cambridge Economic Policy Associates", UK.

5.1.2 Objectives

The purpose of the fiscal policies assignment is to examine the effects of alternative options for pricing diesel, petrol and kerosene and for levying duties on different fuels and vehicles. The effects of the alternative policies on long-term fiscal sustainability, households' expenditure and welfare, vehicle emissions and the environment are assessed.

The main activities of the fiscal policies component of the project, as specified in the terms of reference, are:

- Analysis of the current taxes and prices for relevant petroleum products (diesel, gasoline, and kerosene).
- Investigation of several options for reducing emissions from imported vehicles, including age limits, changing the duty structure (for example, by fuel type combined with vehicle weight; by age) or controlling emissions directly. Consideration of the notion that the reductions in vehicle emissions should be evaluated from the point of view of impact on public health (e.g., exposure to PM_{10} - from primary emissions of PM_{10} and secondary sulphates and nitrates- is of major concern). Analyse the fiscal impact of each as well as likely impact on emissions. Analysis of some options may need to be carried out in combination with fuel pricing measures.
- Evaluation of transport fuel pricing policy and alternative options from the point of view of fiscal impact, reducing vehicle emissions, and impact on the welfare of the poor. Alternative options should include feasible options for reducing the gap between retail prices of diesel and gasoline, possibly in combination with alternative schemes of imposing differentiated vehicle duties. Options to be studied include the following scenarios: (a) raising the price of diesel and lowering (or maintaining at the same level) the price of gasoline in different proportions to narrow the price gap; (b) different designs of a diesel tax, e.g. a tax refundable to bulk users, (c) keeping the price of kerosene comparable to the

price of diesel; and (d) maintaining the current level of kerosene price but taking into account diversion of kerosene to the diesel sector.

- Study of the current tax structure (annual levies) on vehicles and alternative schemes to arrest the current trend of increasing share of diesel-fuelled light-duty vehicles;
- Review of the findings in a form conducive to policy discussion.

5.2 TAXES AND PRICES OF TRANSPORT FUELS AND VEHICLES

5.2.1 Introduction

In the past, the Government of Sri Lanka (GOSL) fixed the final prices of fuels at a level that was intended to reflect the domestic cost of producing these fuels in the local refinery, which is operated by CPC, and the various taxes levied on these fuels. This approach has obvious problems when the international price of crude oil, the input into the refinery, fluctuates both in dollar terms and with the exchange rate, while the retail prices of petroleum products have been changed only infrequently. The danger of this pricing policy is that the government is held responsible for fixing the price of fuels. Any increase is then politically costly and may be delayed beyond the point at which it leads to adverse fiscal and hence economic impacts. Most countries find it politically more attractive to allow import price fluctuations to pass through to final prices and to blame these fluctuations on the international oil market. A counterpart to this is that prices should also fall as well as rise with fluctuations in international prices.

The recent instability in the oil market, illustrated in Figure 5.1 below, combined with a delay in adjusting final prices, caused the oil refinery, CPC, to incur heavy losses in the year 2000, and made the costs of attempting to stabilise the final prices of oil products increasingly unattractive. The GOSL has therefore made a major policy change in the way that petroleum products will be priced in future and proposes to adjust final prices of fuels monthly on the basis of the import parity of the fuels plus allowed margins and the explicit excise taxes. As with other commodities, turnover tax is levied on the tax-inclusive price, while the NSL is levied on the pre-excise tax price. The new system of price setting will ensure that the profits and losses of CPC are separately identified, and the efficiency of CPC can be properly measured against the correct benchmark of world prices.[1] The proposal to change prices monthly is a sensible step in the direction of allowing prices to reflect international conditions, as would happen in a competitive and deregulated market for products. In the absence of the conditions for such a market, frequent price adjustments that lead consumers to expect that prices will adjust, as they do for most other commodities, represent a considerable improvement in policy making.

[1] Note that in the case of products in excess supply domestically the correct reference point would be the export parity price that will be below the import parity price. CPC will therefore receive some protection through transport costs on its domestic sales of these products if the world price is taken as the import parity price as shown. At the margin CPC will have the appropriate incentives to reduce costs or upgrade product to those in excess domestic demand.

5.2.2 Current structure of fuel prices

The fuel price structure as at March 2002 reflects the transition from the old to the new system of pricing. In order to understand the factors behind the current and possible future level of fuel taxation the various components need to be identified and quantified. Conceptually, the opportunity cost of these fuels to the economy is the international price, normally the import price cif Colombo, plus any local costs to deliver the product to the final use. If CPC can match that delivered cost when importing crude oil without taxes, then CPC will be making a net contribution to its owner, GOSL. If so, that profit would be a return on past investment in CPC. If CPC is efficient, this return should be comparable to that on other investments.

The revenue to GOSL from selling fuel in Sri Lanka comes from a variety of sources, which need to be distinguished:

1. Recorded tax revenue, equal to the total collected from excises on fuels and various other taxes such as turnover tax and NSL, [2]
2. The revenue from the difference between the retail price and the import parity cost (CIF + handling + margins) *times* the total consumption of these fuels, *less* the recorded tax revenue. This may be positive or negative.
3. The amount of tax revenue that would have been collected if fuel were taxed like the average other non-fuel commodity (and which, for some purposes it may be desirable to subtract to determine the pure fuel tax element),[3]
4. Notional profits or losses of CPC from refining rather than importing refined products.

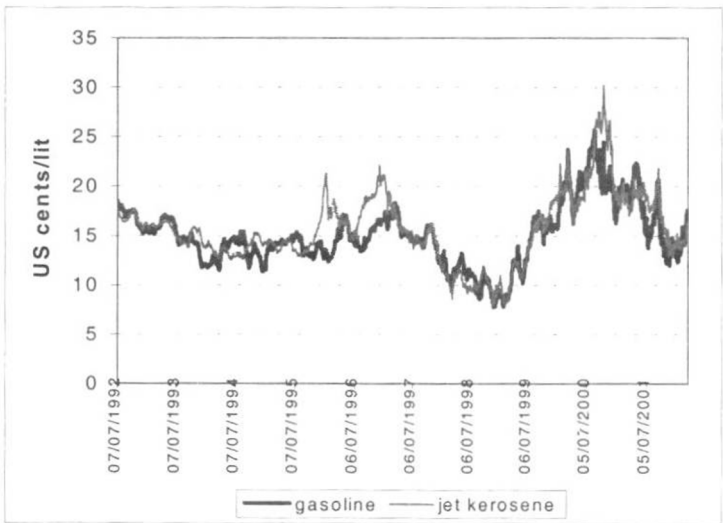


Figure 5.1: Singapore product prices FOB

[2] It is important to keep track of revenue from General Sales Tax, turnover tax and NSL if there is any change in the pattern of expenditure on fuels and other goods, as the share of these in the final price varies. If these taxes were uniform as a percentage of the retail price there would be a case for exempting them and ignoring the impacts of expenditure changes.

[3] Strictly speaking, we are interested in the taxes that would be collected from a marginal increase (of 1 rupee) in expenditure on other goods as a result of a small decrease in expenditure on these fuels, as this will measure the fiscal impact of fuel tax changes from elsewhere in the economy.

To illustrate this proposition, Table 5.1 separately identifies the CPC cost of production (shown as **C** in the table) and the import parity price (**M**). It then identifies the explicit taxes, the resulting discrepancy between the prices that would prevail if taxes were added to import parity prices and the actual price and hence the various sources of revenue per litre. Together with total consumption and production the total revenues can then be computed as shown. Reading down the column for petrol as an example, category 1 recorded taxes per litre are 1.24+24+0.43=25.67Rs/litre (**A**) giving Rs.9.5 billion. Category 2 yields 6.28Rs/litre (**G**) or Rs.2.3 billion. Category 3 amounts to 7.84 Rs/litre (**S**) as the average tax on all other personal consumption, at 16% of the final price. This would have generated Rs.2.9 billion (not shown), so the pure petrol tax is 24.1 Rs/litre (**H**), producing Rs.8.9 billion. Finally, the refinery appears to have production costs that exceed the import parity price, and it therefore loses 2.49 Rs/litre. The 2001 production of petrol was 268 million litres, so the notional loss was Rs. 667 million (**I**).

Table 5.1 shows that in March 2002 the refinery appears to have been losing 1.8 billion Rs. at an annual rate on these products alone (and presumably more if sales of other products were included). If the refinery had been closed, the company had stopped importing crude to refine and instead imported and sold these products, it would have avoided this loss.[4] The table also shows that, although the apparent or explicit tax revenues (**A*Q**) were Rs.20.1 billion, this ignores the additional implicit tax revenue (**G*Q**) of Rs.11.4 billion from the excess of the retail price over the cost of importing to retail. If we also include the losses of the refinery, the budgetary contribution of these fuels and CPC was Rs.29.7 billion, shown as the bottom line of the table. On the other hand, these figures ignore the amount of tax that would have been collected from other goods had the consumers bought these instead of buying fuel. The pure fuel tax element (**H*Q**) is therefore only Rs.19.8 billion (including the implicit tax revenue, ignoring the refinery losses), surprisingly close to the Government target of Rs 20 billion.

The present set of prices meets the Government target that explicit taxes should not fall below Rs 20 billion per year (at 2002 prices, indexed for inflation).[5] CPC has a debt of Rs 16 billion, which the GOSL intends to repay. There were proposals to load more of the debt recovery charges onto petrol than diesel (8.2 Rs/litre for petrol and 5.7 Rs/litre on diesel, compared to the current implicit charges (from cif) of 6.3 and 4.6 Rs/litre shown as **G** in Table 5.1). The same set of proposals included a proposal that these charges should be abolished once the debt had been repaid. There is therefore some ambiguity about the future intended tax structure for these fuels. The working assumption in this report is that the taxes overall implied by the current retail prices is considered appropriate, given the current import parity price. That implies that the

[4] Import duty on crude was abolished in the 2000 Budget, and therefore the costs of production should not include any taxes.

[5] set out in "Government Statement to Promote Public Awareness: Implementation of New Policy for the Pricing of Petroleum Products"

additional revenues of Rs. 9.6 billion will continue. One defence of this is that the 'pure' tax revenue is Rs 19.8 billion, which is about the same as the Government target. Note it does not matter whether they are attributed to CPC or the Government, as losses by CPC are eventually a charge on the exchequer as it is state-owned. It should also be noted that although the current total revenue from fuel sales, including implicit taxes, may be appropriate, the current practice of taxing petrol much more than diesel, or not making all taxes explicit, is not.

Table 5.1: Fuel prices and taxes March 2002

	Petrol	Diesel	Kerosene	Total
M Cif price (Rs per litre)	16.49	15.87	15.02	
T Terminal costs (Rs per litre)	0.019	0.004	0.004	
W Import cost to wholesale = **M+T**	16.51	15.87	15.02	
C CPC cost of production (Rs per litre)	19	16.84	16.98	
CPC profit at import parity prices (Rs per litre) **W-C**	-2.49	-0.97	-1.96	
CPC production (2001) mill litres	268	728	228	
I CPC profits at international prices (Rs billion)	-0.668	-0.703	-0.447	-1.818
	Rs/litre			
N NSL (6.5% of pre-excise wholesale price) =0.065*C	1.24	1.09	1.10	
D Excise duty	24	4	0	
E turnover tax (1% of wholesale) = .01*(**C+D**)	0.43	0.21	0.17	
R margin from wholesale to retail	0.55	0.26	0.27	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	42.72	21.44	16.56	
G implicit tax revenue = **P-F**	6.28	4.56	0.84	
P Retail price (Rs per litre)	49	26	17.4	
A Total explicit taxes = **N+D+E**	25.67	5.30	1.27	
B Total public sector revenues (import parity) =**P-M-T-R**	31.94	9.87	2.11	
S tax at 16% of retail price ("standard" tax)	7.84	4.16	2.78	
H Excess of tax wedge over "standard" tax = **B-S**	24.10	5.71	-0.67	
Q Consumption Million of litres (excl. Power generation)	369	1940	289	
X Expenditure (Rs bill.) = **P*Q**	18.1	50.4	5.0	73.6
Total explicit tax revenue (Rs bill.) = A*Q	**9.5**	**10.3**	**0.4**	**20.1**
Total implicit tax revenues (Rs bill.) = **G*Q**	2.3	8.9	0.2	11.4
Total revenues (explicit and implicit) (Rs bill.) = **B*Q**	11.8	19.1	0.6	31.5
Pure fuel tax revenue (Rs bill.) = **H*Q**	8.9	11.1	-0.2	19.8
Public sector revenues incl profits of CPC (Rs bill.) **B*Q+I**	11.1	18.4	0.2	29.7

Sources: All figures on the table were provided by the local consultant, Dr Sunil Chandrasiri, except for the Cif price (line 1) which was computed as the Fob price, taken from the Energy Information Adminstration web page (www.eia.doe.gov/) plus tanker freight cost, which was provided by Prof. Gordon Hughes from NERA, and Terminal costs (line 2), which were also provided by Prof. Gordon Hughes. Production and consumption (lines 6 and 19 on the Table) were taken from the CPC Statistical Review Annex (provided by CPC officials and yet to be published).

Note: All data on the table corresponds to March 2002 except for the data provided by Prof. Hughes, which corresponds to the year 2000 and CPC production, which corresponds to the year 2001. We had no access to 2002 figures in these cases, but we expect they would be similar.

5.2.3 The international price of oil products

The international price of petrol and jet kerosene (which is a reasonable proxy for road diesel) fob Singapore is shown in Figure 5.1. It shows that per unit volume they are priced very closely, averaging about 15 cents/litre with fluctuations between about 10 and 20 cents/litre from 1992 (after the Gulf war shock) to 1999. For reference, 15 cents/litre is $200/metric tonne (mt) for petrol (RON 90), and $190/mt for kerosene.

From the second half of 1999 to the middle of 2000, petrol and kerosene moved sharply higher to an apparent new level somewhat above 20 US cents/litre ($250-275/mt), starting to fall in December 2000. Prices fell back towards 15 cents/litre, but have increased again in 2002. It was outside the scope of this project to forecast the long-term trend movement of the price of oil or future movements of the price. Our estimates are based on the prices ruling in March 2002; it is assumed that prices will remain at these levels.

It is worth noting that in 1996 the price of petrol in Sri Lanka was 50 Rs/litre when the fob Singapore price was 15 cents/litre, which at the exchange rate of 55 Rs/$ was 8.3 Rs/litre. The costs of transport and handling from Singapore to Colombo (cif) are 1 US cent/litre, or 0.55 Rs (1996) /litre. Margins to retail might be a further 0.5 Rs (1996)/litre,[6] making the tax take 50-9.4 = 40.6 Rs (1996)/litre. The RPI has increased by 90% between 1996 and 2002, so that to maintain the same real tax revenue in 2002, government receipts should increase to 77 Rs/litre. The 2002 cif price is 16.49 Rs/litre (from Table 5.1), and the cost to retail is a further 0.57 Rs/litre. The petrol price has been reduced to 49 Rs/litre, making the total tax revenue (line **B** in Table 5.1) 31.94 Rs/litre. Consequently, the real tax revenue per litre of petrol to the GOSL has declined sharply. To maintain the 1996 real tax revenue per litre the retail price would need to be increased to 94 Rs/litre. Revenue from current sales of petrol would have increased by about Rs.10 billion if the real tax per litre had been maintained (allowing for the decline in petrol use that would result from the higher price, and assuming a long-run price elasticity of –0.4).

In 1996 the bulk price of diesel was increased to 13.2 Rs/litre, while the Singapore kerosene fob price was $220/mt = 9.6 Rs/litre.[7] Arguing as above, the cif price would be 10.1 Rs/litre and the cost to retail would be 10.3 Rs/litre. The tax take was therefore about 2.9 Rs. (1996)/litre or 5.5 Rs (2002)/litre. The March 2002 price of diesel was 26 Rs/lt or nearly double the 1996 price (though an increase of only about 4% in real terms), while the March 2002 Singapore fob price of kerosene was $200/mt = 14.9

[6] This is taken as 1% of the retail price, as in 2002, on the advice of Dr Chandrasiri.

[7] We have neither the cif diesel price in Sri Lanka nor the Singapore fob diesel price, so the Singapore kerosene price is a proxy. Kerosene is normally about 3% more expensive than diesel.

Rs/litre, 55% higher in nominal terms. (The exchange rate has depreciated less, by 70%, over this period, so there has been a real appreciation of the Rupee.) The current total tax take is 9.9 Rs/litre (line **B** in Table 5.1), or a real increase of 80%. The balance of taxes between diesel and petrol has therefore improved since 1996. The extra revenue from raising the real tax rate on diesel to the 1996 level would be Rs. 8.3 billion (assuming an elasticity of -0.1).

Even allowing for the increase in diesel tax revenues, the overall effect of adjusting the prices of diesel and petrol has been to reduce real fuel tax revenues from petrol and diesel by about Rs. 1.8 billion, suggesting that some modest increase in average fuel tax rates might now be appropriate on fiscal grounds. It also confirms the desirability of maintaining the present implicit taxes, and logically converting them into higher explicit excise duties.

5.2.4 The taxation of motor vehicles

The proper taxation of road fuels must balance a number of conflicting objectives. In developing countries petrol taxes are an attractive way of taxing the expenditure of the wealthier citizens who can afford cars. Most (but by no means all) developed countries find that income taxation and/or Value Added Taxes are better than petrol taxes on revenue and redistributional grounds, but in developing countries these may have higher administrative costs and, possibly, lower compliance. As diesel fuel is properly used in commercial vehicles as an input into production rather than final consumption, it should not be taxed on revenue raising or redistributional grounds, and is therefore typically taxed at lower rates. The problem this causes in encouraging domestic consumers to avoid the heavy petrol taxes by buying diesel vehicles has already been noted.

In addition to these revenue-raising reasons, road users are taxed to cover the cost of road use and environmental damage caused by vehicles. Fuel excise duties are the simplest way to charge for road use, as they are distance-related charges. They are similarly the simplest way to charge for pollution. In neither case are they ideal, for different vehicles impose very different road costs per litre of fuel. CO_2 emissions are directly proportional to fuel use, and it does not matter where the fuel is consumed, but for other pollutants, the damage depends on where the emissions occur. Thus SO_2 emissions depend only on the sulphur content of the fuel, and not the characteristics of the vehicle. The damage is higher in populous urban areas and still wind conditions. Emissions of other pollutants, notably particulates, PM, depend very much on the vintage, type and condition of the vehicle, while the damage again is location and time specific.

Other tax and regulatory instruments are needed to improve the targeting of these two costs. Annual licence fees can be made vehicle-specific, for example to cover the extra road and pollution costs not already charged through the fuel excise duties. Initial registration fees (and import duties) are a way of capitalising these annual charges into a single sum. Annual fees that depend on measured emission levels and other characteristics that influence pollution damage (age, diesel vs petrol, two-stroke vs four-stroke) provide incentives to replace more costly vehicles earlier and hence improve the characteristics of the vehicle fleet. Regulations that ban certain types of vehicle (two-stroke motor cycles, diesel-power vehicles under 1.5 tonne, etc) have the effect of reducing the damage of newly purchased vehicles, but encourage owners of existing vehicles to retain them for longer as their scarcity value increases. Annual vehicle inspections combined with emissions standards can also remove the possibly small fraction of highly polluting vehicles that cause the majority of pollution from the vehicle fleet. Fuel reformulation and standards on levels of sulphur can have a direct effect on the emissions of these pollutants, but may be costly to deliver.

The conclusion of this cursory list of instruments and an assessment of their likely impact on fuel and vehicle choice and emissions levels suggest that fuel taxes have an important role to play but cannot possibly deal with all the problems. The guiding principle for setting fuel excise duties is to build up the total from the three component elements:

- the charge for road use,
- the emissions charge,
- the pure tax part.

Each of these varies across vehicles, and requires identifying the representative vehicle for which the fuel excise is to be set. This will depend on the effectiveness of other complimentary instruments to recover the shortfall in justified taxation on different vehicle. As a rule of thumb that may work well if these other instruments can be freely set, petrol would be taxed for the representative private car, and diesel for smaller trucks (providing they and lighter vehicles represent a reasonable fraction of total diesel fuel consumption). The aim is to ensure that the fraction of vehicles that are seriously overcharged is small, and that given the other instruments and their rates, the degree of undercharging is also modest or low.

5.2.5 Revenue–neutral tax rebalancing

The present structure of taxes on petrol, diesel and kerosene discriminates against petrol consumption, although the imbalance has been considerably reduced since 1996. A study of the correct level of petrol and diesel taxes requires an estimate for the proper level of road user charges and pollution, before determining the amount extra to charge petrol for revenue raising and redistributive purposes. We lack an up-to-date road user charge study for Sri Lanka, and would suggest that future fuel tax reforms be informed

by commissioning such a study, or updating past studies to reflect traffic growth and road maintenance costs. Rather than determine the optimal level of petrol and diesel taxes, we instead consider various adjustments to their level that leave the current tax revenue unchanged.

The main concern with higher petrol than diesel taxes is that it may encourage a switch to diesel use, thwarting the revenue raising purpose of the petrol tax, and increasing pollution. If diesel taxes were raised to prevent this, then commercial uses may be over-taxed (depending on whether current diesel charges cover road costs), and kerosene adulteration of diesel fuel might become a problem. This in turn points to a corresponding increase in kerosene taxation but this would be politically difficult. The first question is then whether the current pattern of prices encourages either adulteration of diesel or fuel switching, or both.

5.2 6 Adulteration of diesel by kerosene

One of the obvious concerns with under-pricing kerosene relative to diesel is that there will be profitable adulteration of diesel by kerosene. This will reduce tax revenues, undercharge diesel vehicles, and weaken the case for substantial increases in the price of diesel without commensurate and politically costly increases in the price of kerosene. Mario Camarsa, has made estimates for Enstrat International Ltd of *expected* consumption of petrol and diesel using estimates of vehicle km travelled by type of vehicle and fuel. In Table 5.2 the actual consumption is compared to the expected consumption. The comparison indicates that there is little if any adulteration. That is reassuring, although the current price differences between kerosene and diesel are modest, and adulteration may become more serious if it were to widen appreciably.

Table 5.2: Inventory Model Predicted vs Actual Transport Fuel Demand (Year 2000 - t/yr)

	Actual	Model Predicted	% Difference
Petrol	225,000	245,000	8.9%
Diesel Fuel	1,316,000	1,362,000	3.5%

Source: Enstrat International Ltd

The over-prediction of petrol consumption may indicate that some petrol-powered vehicles are using LPG, which may amount to 4% of total petrol consumption.

5.2.7 Diesel and petrol consumption

Figure 5.2 shows petrol and diesel consumption for the period 1990-2002.[8] The average annual rate of growth of auto diesel consumption was 10% whilst that of petrol was only 3%. The elasticity of fuel consumption with respect to GDP is 1.9 for auto diesel and only 0.6 for petrol. The graph reveals that diesel use has grown far more rapidly than petrol and the share of petrol in total road transport fuel has fallen from 30% to 18%. This might suggest that the relatively high price of petrol to diesel has caused fuel substitution, leading to a loss of fiscal revenue and an increase in pollution.

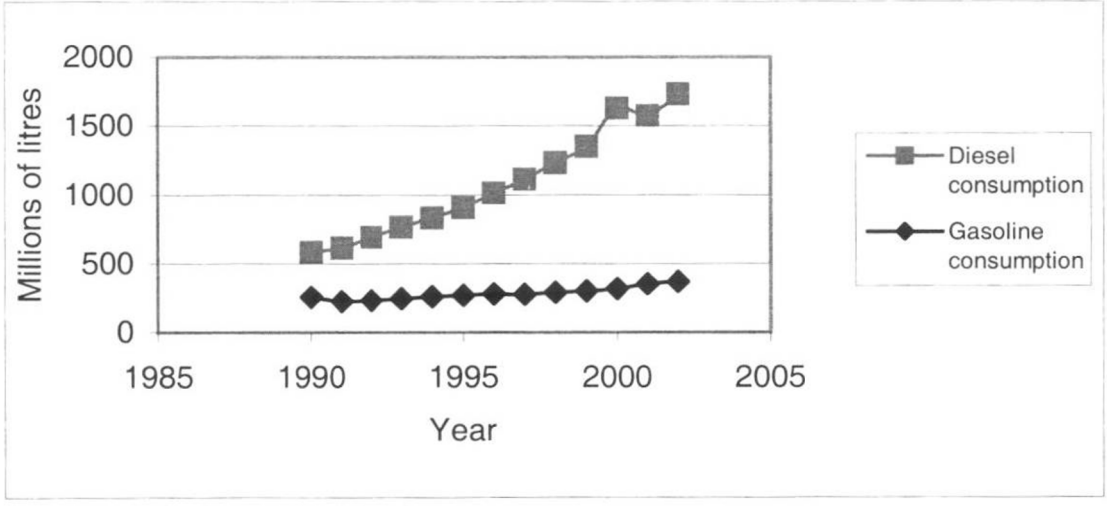


Figure 5.2: Diesel and petrol consumption

The story is, however, rather more complicated than this simple graph suggests. In the absence of higher taxes on diesel, one would expect pickups/dual purpose vehicles (i.e. light duty vehicles, LDVs) to choose diesel as the cheaper option. In Sri Lanka the percentage of cars running on petrol has remained reasonably constant at around 90%, but for LDVs the share of petrol has fallen steadily from 35% to 10%. The fastest growing sector of the diesel consuming market has been in LDVs, so the rapid rise in the diesel share is the result of rapid growth in the potentially diesel-using LDVs with an increase in the share of these vehicles that actually use diesel.

Data on first registration allows us to examine the factors behind these trends. Figure 5.3 shows that the fraction of petrol cars fluctuates between 0.6 and 0.9, with the recent figures suggesting a shift down to 0.7. That suggests that over time the share of diesel

[8] Figures for the years 2000 and 2001 are provisional and were provided by CPC. Figures for the year 2002 are predicted figures on the basis of the average growth rate in the consumption of each fuel for the period 1998-2000.

in the total stock of cars will rise from its present level unless the share of diesel in new registrations falls.[9]

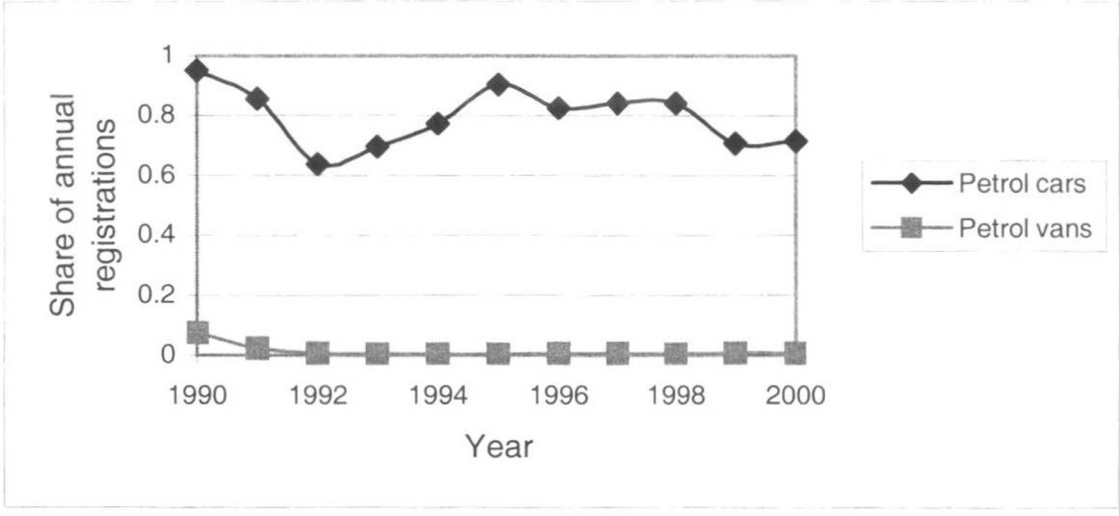


Figure 5.3: Share of petrol cars and vans in annual registrations

Periodically favoured groups (civil servants and academics) are allowed to import vehicles and pay duty at a concessionary rate of 25% (regardless of fuel). This concessionary rate replaces the customs duty, the customs surcharge and the excise duty, which typically add to around 146% of the import price of diesel cars net of taxes and to 92% of the import price of diesel vans net of taxes (see Table 5.3). If they choose not to make direct use of this concession, they can sell the permit (and the market clearing price for permits is apparently 75,000 to 100,000 Rs), ensuring that a vehicle will be imported as a result of each permit issued. This would certainly bias the choice towards diesel cars in years when the concessions were granted. The system was abolished in 1994, reintroduced in 1998 and stopped again in 2000. The number of diesel cars jumped up from around 800 per year before 1998 to over 4000 from 1999-2000, or from 16% to 29%. If the concession remains withdrawn, then the share of diesel cars might fall back to its earlier level and remain stable.

One other factor affecting annual registration of diesel cars is changes in the special annual tax for diesel vehicles (which was Rs.5000 from 1997 to November 2001, and then abolished, though Table 5.3 shows that the differential annual license fee is still Rs 1000 more for diesel). The second is the relatively cheaper prices of diesel compared to petrol (diesel was increased in price before the annual diesel tax was abolished). Taken together, these effects here favour petrol cars, so again, there are no strong reasons for expecting an increase in the future share of diesel cars.

[9] The customs web page http://www.customs.gov.lk/guides/tariff gives the nominal rate of excise duty as 65% for diesel cars and 35% of diesel dual purpose vehicles but the actual computation of the amounts payable are more complicated that simply taking these percentages on the import price. The actual amounts payable according to the full formula are given in Table 5.3 below.

Table 5.3: Price structure for petrol and diesel cars and vans

	Average import price net of all taxes Rs '000	Customs duty (CD) %	Surcharge as % of CD	Excise duty (%)	GST (%) of tax inclusive price	Stamp duty % of cif price	NSL (%)
Toyota Corolla diesel car	813	25	40	65	12.5	1	6.5
Toyota Corolla petrol car	573	25	40	15	12.5	1	6.5
Nissan Sunny diesel car	847	25	40	65	12.5	1	6.5
Nissan Sunny petrol car	675	25	40	15	12.5	1	6.5
Large diesel car	1770	25	40	65	12.5	1	6.5
Large petrol car	1105	25	40	15	12.5	1	6.5
Toyota Townace diesel van	500	25	40	35	12.5	1	6.5
Toyota Townace petrol van	382	25	40	15	12.5	1	6.5
Nissan Vennet diesel van	385	25	40	35	12.5	1	6.5
Nissan Vennet petrol van	370	25	40	15	12.5	1	6.5
	Rs '000	Rs '000	Rs '000	Rs '000	Rs '000	Rs '000	Rs '000
Toyota Corolla diesel car	813	203.25	81.30	902.50	251.02	82.57	8.13
Toyota Corolla petrol car	573	143.25	57.30	137.44	114.59	58.20	5.73
Nissan Sunny diesel car	847	211.75	84.70	940.24	261.52	86.02	8.47
Nissan Sunny petrol car	675	168.75	67.50	161.90	134.99	68.55	6.75
Large diesel car	1770	442.50	177.00	1964.85	546.51	179.77	17.70
Large petrol car	1105	276.25	110.50	265.04	220.98	112.23	11.05
Toyota Townace diesel van	500	125.00	50.00	287.15	120.89	50.78	5.00
Toyota Townace petrol van	382	95.50	38.20	91.63	76.39	38.80	3.82
Nissan Vennet diesel van	385	96.25	38.50	221.10	93.09	39.10	3.85
Nissan Vennet petrol van	370	92.50	37.00	88.75	73.99	37.58	3.70
	Final price inc. all taxes and duties Rs '000	Ratio of price after tax to cif price	Registration charge Rupees	Annual license fee Rupees			
Toyota Corolla diesel car	2341.77	2.88	1650	2800			
Toyota Corolla petrol car	1089.50	1.90	1650	1800			
Nissan Sunny diesel car	2439.71	2.88	1650	2800			
Nissan Sunny petrol car	1283.45	1.90	1650	1800			
Large diesel car	5098.32	2.88	1650	2800			
Large petrol car	2101.05	1.90	1650	1800			
Toyota Townace diesel van	1138.82	2.28	1400	2800			
Toyota Townace petrol van	726.34	1.90	1400	1800			
Nissan Vennet diesel van	876.89	2.28	1400	2800			
Nissan Vennet petrol van	703.52	1.90	1400	1800			

Source: Dr Sunil Chandrasiri, March 2002

Figure 5.4 shows the share of diesel and petrol cars for the period 1990-2000. The share of diesel cars in the total car fleet has remained at around 10%. Despite temporary jumps in annual registrations mainly due to the concessionary import tax, there does not seem to be a problem in the proportion of cars run with diesel.

The more serious problem is the rapid growth in pickups and dual purpose vehicles, i.e. light duty vehicles, LDVs. This is shown in Figure 5.5. In the UK, where petrol and diesel are taxed at the same rate, the share of petrol LDVs is only 21%, but much depends on what vehicles fall in this category, and to what extent their buyers are choosing diesel LDVs as satisfactory but more economic alternatives to petrol cars. The rapid growth of dual purpose vehicles suggests there has been substitution of vans for cars.

In the case of LDVs, there are essentially no petrol-powered LDVs newly registered after 1992, so the erosion in the share of petrol powered LDVs is readily explained by the registration data, and can be expected to continue.

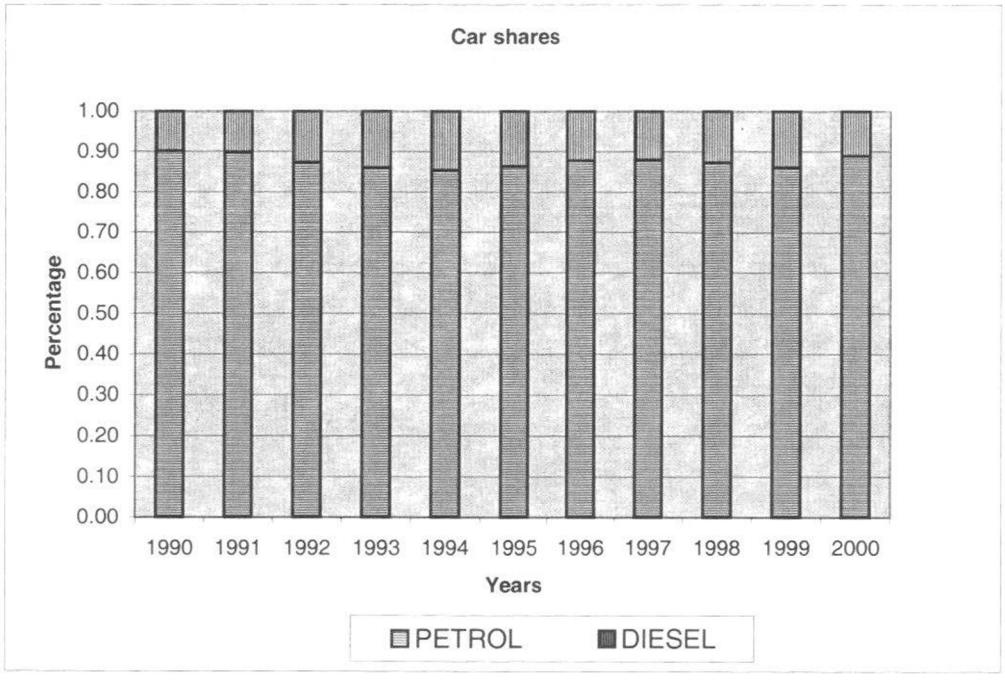


Figure 5.4: Shares of petrol and diesel cars for the period 1990-2000

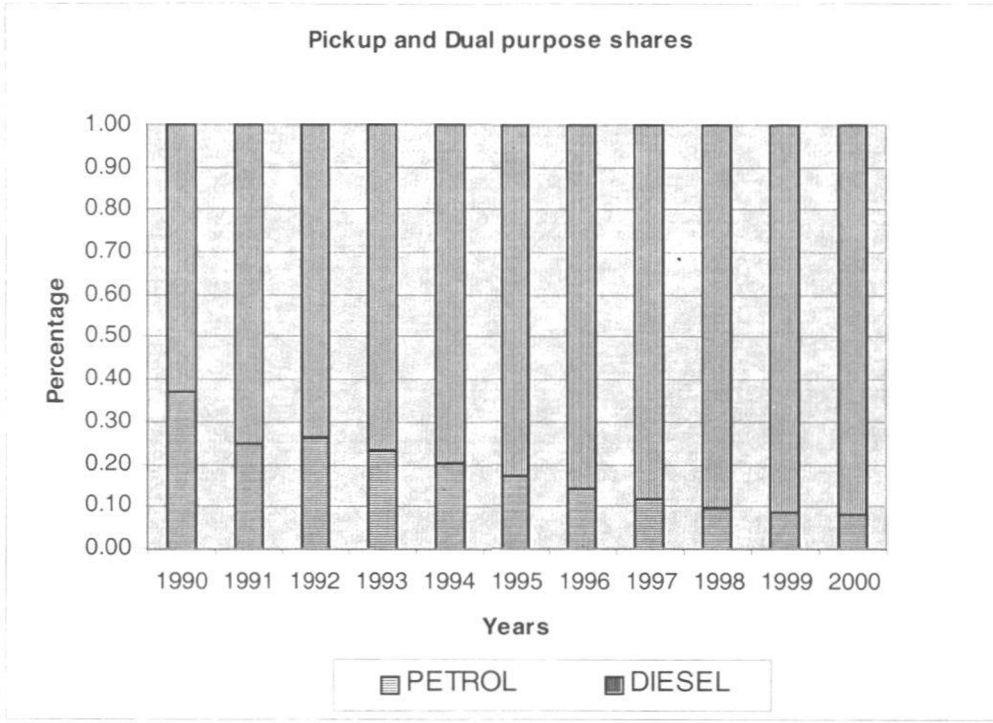


Figure 5.5: Shares of petrol and diesel vans for the period 1990-2000

All of this evidence would suggest that the current discrimination against petrol does not have large effects on the choice of fuels for any given vehicle, and probably does not have much effect on the choice of vehicles – there is limited substitutability between cars and other non-car diesel powered vehicles, and limited substitutability between light and heavier trucks. Part of the reason is that diesel powered vehicles are more expensive for a given power than petrol-powered vehicles, and the differential in price must be sufficient to offset this additional cost.

The next section discusses the break-even distance that must be driven under various tax scenarios to make the choice of diesel-powered vehicle cheaper than petrol. On that basis one might expect a higher fraction of cars to be diesel-powered. The possible explanations are that most cars are bought second hand from Japan, where taxation does not favour diesel powered cars. As a result, most second hand cars will be petrol powered and relatively cheaper than second hand diesel cars. The other reason is that smaller cars are less likely to be diesel-powered than larger cars given the cost disadvantage, and in general cars in Sri Lanka are likely to be smaller than in developed countries.

The situation could change as the world car manufacturers develop cheaper and smaller diesel-powered cars, but the situation can be readily addressed without changing the prices of transport fuels by imposing additional registration charges on diesel powered vehicles, or annual license charges. The second method is preferable, when the composition of the existing vehicle fleet is the main problem, as it can be combined with a differential charge to reflect the pollution characteristics of the vehicle, though it

is likely to be politically more difficult. More recent models have lower emissions and this could be reflected in age-related licence fees. It has the further advantage that the amount of the charge would be lower, and would provide an immediate incentive to scrap older vehicles and replace them with the now considerably cheaper newer and less polluting vehicles. Politically, however, it is less attractive, as the initial registration fee is paid only once and may be concealed in the initial purchase price, while the annual license fee is very prominent to motorists.

5.2.8 Break-even point analysis

The aim of a break-even analysis was to determine the number of kilometres at which individuals would be indifferent in terms of total annual operating costs, between buying a diesel-engine car or van rather than a petrol-engine car or van. The efficient choice of vehicle type is the choice that minimises the life-time cost (for given quality and suitability of vehicle) only including those taxes that reflect true social costs. For any given size and weight of vehicle, where road damage and congestion are the same, the main extra social costs that need to be taken into account are the higher pollution costs of diesel compared to petrol.

In Section 5.5 we provide rough estimates of the pollution damage cost for diesel, which might average as much as 1.5 Rs/litre higher than petrol, depending on sulphur content. Raising the price of diesel to reflect this damage cost through a pollution tax will increase the break-even distance at which diesel becomes cheaper. We therefore contrast three cases – the present situation with all taxes, a reference undistorted (but uncorrected) case with no taxes on fuels or vehicles, and an efficient case with a pollution tax case of 1.5 Rs/litre. The reason for distinguishing undistorted and efficient cases is that the proper estimate of the cost of pollution is subject to a very wide margin of uncertainty, and it would be unwise to base policy on this number without further careful analysis. The break-even distance at which diesel and petrol are equally costly is then the break-even point. The object of changing the various taxes, license fees, registration fees and import duties, is to shift the market-determined choice of vehicle towards the efficient choice.

The current situation starts with the current (as in March 2002) final price of cars and vans, including all taxes and duties, together with their annual operating costs and the current prices of petrol and diesel with current taxes. Three cases were analysed:

a) Base case. Current prices, including all taxes for fuels and vehicles (Rs 49 per litre of petrol and Rs 26 per litre of diesel plus all current taxes on import price of vehicles),
b) No tax case. Prices at import parity without any taxes on fuels or vehicles (Rs 17.06 per litre of petrol and Rs 16.13 per litre of diesel, and the prices of vehicles without taxes.

c) Pollution tax of 1.5 Rs/litre on diesel and no other taxes

Two decisions were modelled

i) Whether to buy a diesel or petrol powered vehicle when buying a specific type of vehicle (car or van)

ii) Whether to buy a diesel van rather than a petrol car

The first choice was analysed for three types of cars (Toyota Corolla, Nissan Sunny, and a large but unspecified car), all of them 2 years old, and for two types of 5-year old vans (Nissan Vennet and Toyota Townace). The second choice is between a 2-year old petrol Nissan Sunny and a 5-year old Toyota Townace, (medium car - medium van). The results are summarised in Table 5.4, and the assumptions on which the table is constructed are given in the appendix. The question whether different taxes would encourage existing vehicle owners to convert their engine to the efficient choice is discussed below.

The assumptions on which the results in Table 5.4 are set out critically influence the results in the following way. Diesel-engined vehicles are typically more costly to buy but cheaper on fuel to run, though in Sri Lanka they possibly have higher maintenance costs per km, and are usually more durable. The question whether it is cheaper to buy diesel or petrol therefore depends on the differential cost per km, which depends on whether the life of the vehicle is determined purely by age regardless of distance, or distance regardless of age, or some combination. If age is the sole determinant, the differential capital cost per km decreases rapidly with distance per year, but not if life depends on distance. The working hypothesis on which the calculations of Table 5.4 are based is that life depends on distance, not age. The reason is that the climate in Sri Lanka involves no frost, and hence no salt on roads, which leads to corrosion and age-related failure. It seems more likely that the quality of roads will be the prime determinant of life, and hence that distance is the key factor. If this hypothesis is incorrect, then the results will need to be re-examined.

Other factors also influence the outcome in less predictable ways. The comparisons are based on comparable vehicles (for which there are similar petrol and diesel versions) and which are currently popular in Sri Lanka. The results depend sensitively on fuel consumption, which may vary with local conditions, driver performance, and fuel quality. Thus diesel efficiency is relatively better in urban stop-start driving conditions, and to that extent are more likely to be economic in Sri Lanka than the assumed fuel consumption figures indicate. Vehicle technology is continually changing, and the relative cost and performance of diesel engines has improved rather more quickly than petrol engines recently as they have increased their world market share. Vehicles differ in their performance, cost, fuel efficiency, durability, and consumer appeal, so it is intrinsically difficult to compare more than a small number of vehicles that are of similar appeal and different fuels, and even more difficult to compare choices between

cars and vans. At best the comparisons may identify gross distortions that the current set of taxes induce in vehicle fuel and type, remembering that actual choices will cover a far wider range than illustrated here. Further, all vehicles are purchased second-hand, and their prices will depend on supply and demand in the second-hand market in Japan (somewhat influenced by foreign demand of which Sri Lanka is a part). Relative prices are likely to change over time as supply and demand change in response to economic conditions and environmental regulations. Current prices and choices are only a rough guide to the future.

The table is read as follows. At present prices and taxes, it would be cheaper to buy the petrol version of any car (the Toyota Corolla, Nissan Sunny, or the generic large car). This would continue to be true with no taxes (on the whole range of import price assumptions) and with just pollution taxes (but no import duties or differential registration fees). The current decision is therefore correct (="yes" in last column), as changing the current taxes to reflect only the pollution differential would not alter this choice. Apparently the current tax system (and particularly combined with the heavy *ad valorem* element on the extra cost of diesel vehicles) does not appear to distort the choice of car type. The fact that most (90%) cars that are registered are petrol is therefore reassuring in confirming our analysis.

Table 5.4: Break-even distances at which buying a petrol or diesel vehicle is equally costly

Vehicle and choice	Choice with: Current taxes	No taxes	Pollution tax only	Km/year Annual distance driven		Correct decision at present?
				Petrol	Diesel	
Toyota Corolla G or D	Always G	Always G	Always G	15,000	20,000	Yes
Nissan Sunny G or D	Always G	Always G	Always G	15,000	20,000	Yes
Large Cars G or D	Always G	Always G	Always G	15,000	20,000	Yes
Nissan Vennet G or D	9,000	Always G	Always G	15,000	20,000	No
Toyota Townace G or D	19,000	Always G	Always G	15,000	20,000	Probably No
2-yr Nissan Sunny or 4-yr Toyota Townace	Always van	Always van	Always van	15,000	20,000	Yes

Source: own calculations from data in appendix

When we come to the choice of van type, petrol versions would only be favoured for a 5-year old Nissan Vennet vans if they drive less than 9,000 km/yr. As they drive typically more than that the choice would be diesel, although the efficient choice should be petrol (with or without the pollution tax). Current prices and taxes therefore make the choice incorrect, indicated by a "No" in the decision column. On the other hand,

there is more chance that a buyer would prefer the petrol version of the Toyota Townace, particularly if he expected to drive the normal distance for a petrol car. That choice would be correct. If, on the other hand, the buyer planned to drive the normal distance for a diesel vehicle, it would appear cheaper to buy the diesel version, which is the incorrect choice. As we do not know what fraction of buyers choose the petrol version we cannot be sure that the decision is incorrect at present taxes and prices, but as it seems likely that most vans purchased are diesel, we have indicated that it is probably not correct, hence "Probably No". When comparing a choice of older vans to newer cars, buyers are likely to make the efficient choice of the older van (though they would choose the diesel rather than the petrol version). This choice is only relatively efficient if the choice is restricted to cars that cannot be older than 2 years while vans can be 5 years old. If older cars could be bought cheaply instead, they may be chosen in preference to vans, and would then be likely to be petrol powered. The fact that almost all vans are now diesel by choice means either that owners of larger vans expect to drive more than 19,000 km/yr, or one of the other assumptions is incorrect. The fact that breakeven distance is so close to the actual average annual distance of diesel vans means that small changes in other assumptions would readily explain the observed choice.

The observation that the efficient choice of van may be petrol rather than diesel reflects the particular type of van considered. Both models have windows and are perfectly satisfactory people carriers, rather than the traditional model of windowless cargo-carrying vans that the term normally connotes in Europe. It may be that the licensing and taxation rules should more carefully distinguish between vehicles that are only likely to be useful for commercial purposes (single driver carrying goods), and those that are well-suited for carrying passengers (and should be classified as private vehicles or vehicles for hire). The Nissan Vennet is also interesting in that the differential price of the diesel version is low, and the saving on fuel costs at current tax levels greatly outweighs the higher maintenance cost. With no fuel taxes, the higher maintenance cost would more than compensate for the greater fuel efficiency, making any increase in purchase cost (per km) of the diesel version relative to the petrol version decisive in rejecting the diesel version. To that extent the current favourable tax treatment of these kinds of vans combined with the heavier taxation of petrol induce inefficient choices. The Toyota Townace has a higher differential diesel purchase price that is amplified by the import tax regime, and this counteracts the effect of the lower fuel costs until a higher annual distance, so it is less clear that buyers will always choose the wrong fuel type. If, on the other hand, the maintenance cost of diesel vans were lower than that of petrol vans, then the choice would probably be diesel.

The next question is whether there is an incentive to import petrol powered vehicles and then retrofit them with diesel engines. In the case of cars, if the owner wishes to subsequently change the engine from petrol to diesel, an extra registration fee of Rs. 350,000 is payable. Much then depends on the cost of conversion. The data from

Pakistan suggests that the conversion cost is only Rs. 16,000, which seems very low. In particular, the difference in pre-tax import price of diesel and petrol versions is considerable greater than this cost. This seems improbable, as it must be cheaper to make the choice of engine at the factory, and avoid the loss of a perfectly good engine, quite apart from the extra cost in labour of making the change. If we take the cif import price difference as a better measure of the cost of conversion, then the breakeven annual distance at which conversion to diesel is profitable is over 100,000 km for the Corolla, 27,000 km for the Sunny and 23,000 km for a large car. In such cases conversion is unlikely to be profitable. If we take the conversion cost as only Rs 16,000, then conversion is attractive at an annual distance of 19,300 km for the Corolla, 14,300 km for the Sunny, and only 6,400 km for a large car. In these cases, conversion looks marginally attractive for larger cars (though here surely the cost of conversion would require a larger engine, so this figure of Rs. 16,000 regardless of size must be suspect).

The evidence we have is that all vans are already diesel when imported, so the issue does not arise in that case. The customs department considers that the result of the high registration fee payable on conversion is that very few such registered conversions now occur.[10] The appropriate solution to inefficient conversion is first, to subject diesel engines to the same import tax regime as diesel-engined vehicles, and then to impose an additional registration charge, as at present, when converting from petrol to diesel.

As there is considerable uncertainty about whether engine conversion is practised in Sri Lanka (possibly evading the extra registration fee), we suggest that a survey be done of existing car to establish the fraction of each cohort of vehicles (by age and date of import) that are currently diesel powered, and if possible, their original import engine specification. As recent changes have all been in the direction of reducing the differential between the price of petrol and diesel, it seems unlikely that there will be a problem now unless there has been in the recent past.

5.2.9 Motorcycles

In Section 5.5 we estimate the pollution costs of motorcycles. Two-stroke motorcycles appear to have higher pollution costs of possibly as much as 140 Rs. per thousand km in urban areas. If the idea is to reflect this additional social cost in an annual licence fee, then taking an annual distance driven of 5,000 km/yr, the *extra* cost (which might possibly be reflected in an annual license fee) could be as much as 700 Rs/yr. On the other hand, it appears that the extra capital cost of a four-stroke motorcycle is 10-15% higher than a two-stroke motorcycle, while the fuel efficiency is nearly 20% better (62km/litre for a 100cc four-stroke motorcycle compared to 52km/litre for the two-

[10] It is possible that all such conversions are now unregistered and illegal, but if so the remedy is to enforce the law and fine those without the registration documents.

stroke 100cc version).[11] Two-stroke fuel needs additional additives that further increase the fuel cost, though they may have somewhat lower maintenance costs as they are simpler. Assuming that the extra fuel additives offset the lower maintenance costs, two-strokes would have higher running costs but lower capital costs. At modest annual distances such as 5,000 km, and a vehicle life of 75,000 km, the two-stroke version would cost about Rs. 1,700/yr less to operate with current prices and taxes. The annual *social* cost (allowing for the lower capital cost of two-stroke motor-cycles but the higher pollution costs) of the two-stroke version is still at least Rs. 500/yr less than for four-stroke versions at these distances. At an annual distance of 10,000 km current taxes slightly favour two-strokes but their social cost could be Rs. 300/yr higher. Current taxes and registration/license fees do not therefore seem likely to seriously distort the choice of motorcycles.

If part of the problem is that the current very high *ad valorem* import duties amplify the price advantage of two-stroke motorcycles, and if that structure is retained, it will need to be offset either by higher annual fees (which encourage the current stock to change sooner) or higher registration fees for two-stroke motorcycles. As shown in Section 5.5, there is not strong case for banning the further import and registration of two-stroke vehicles. Increasing the annual license fee on two-stroke compared to four-stroke motorcycles would not encourage four-strokes unless their prices fell considerably. Given the difficulty of measuring pollution costs and estimating emissions from motor cycles, it would be difficult to defend an increase in the annual license fee. Perhaps the most important action is for the Government to check that prices for four-stroke motorcycles are at competitive levels, and carry no higher mark-ups than for two-stroke motorcycles. There have been suspicions that four-stroke motorcycles are considered luxury versions that can attract higher profit margins. Given their better fuel efficiency, which would help but may not be sufficient to encourage current buyers to choose four-stroke motorcycles. A modest increase in the initial registration fee for two-stroke cycles (of perhaps Rs. 700) might help.

[11] Fuel consumption data for 125 cc motor-cycles in the UK suggest rather lower figures of 26-29 km/litre for two-stroke and 32-35 km/litre for four-stroke motorcycles. The difference will affect the relative cost of the two types of vehicles, though not the extra pollution cost, which is based on emissions per km. If the fuel consumption is taken as 26km/litre for two-stroke and 31km/litre for four-stroke motorcycles, then four-stroke motorcycles would be cheaper per km over their lifetime.

5.2.10 Where is the problem?

Diesel consumption has substantially increased both in absolute and relative terms in the last decade. There are sound technical reasons that justify diesel-powered lorries and buses. The share of diesel cars with respect to the total number of cars has remained constant at roughly 10%. Temporary increases seem to be mainly due to concessionary import licenses, which have now ended. The main source of increase in diesel consumption has been the increase in both the share and the vehicle kilometres travelled (VKT) of vans, pickups and dual-purpose vehicles. The reasons behind this trend seem to be the following:

a) The final price of diesel has never been much more than half the final price of petrol.
b) A dual-purpose vehicle is a moderately close substitute for a car, depending on the price difference. The price of a diesel dual-purpose vehicle can be lower than the price of a car. The reason for this price difference is threefold:
    i) Imported cars cannot be older than three years, whereas imported vans cannot be older than five years. The import price net of taxes is therefore lower for vans, if anything, because they are older. The notional base to compute import and excise duties is therefore lower.
    ii) The excise duty rate is apparently 111% of the import price for diesel cars and 57% for diesel dual-purpose vehicles.
    iii) The customs duty and the surcharge as percentage of customs duty rates are the same for both vehicle types.

    The cumulative effect of (ii) and (iii) results in that the average final tax paid on imported diesel cars is 146% of the import price net of taxes whereas the average final tax paid on imported diesel dual purpose vehicles is 92% of the import price net of taxes.
c) The annual license fee is the same for both diesel cars and dual-purpose vehicles.
d) The registration charge is higher for diesel cars than for diesel dual-purpose vehicles.

Table 5.3 gives the current price structure for petrol and diesel cars and vans in rates and thousands of Rupees. The exact formulae used are presented in the Appendix (and in many cases the percentages cannot simply be applied either to the cif price or to the cumulative tax inclusive price to that stage).

Our tentative conclusions are that the current system of import duties tends to offset the effects of the preferential pricing of diesel, where consumers are comparing vehicles of the same type but different engines (petrol or diesel). The very high rates of *ad valorem* import duties encourages consumers to bias their choices towards cheaper alternatives,

and the import regime then favours diesel vans over petrol cars. The problem of pollution is therefore one of vehicle maintenance, possibly of fuel quality, and the encouragement offered by the import regime towards older and more polluting vehicles.

Having some idea of where the problems lie and where the policies should be directed, we are now in a position to formulate different policy options. This is the subject of the next Section.

5.2.11 Conclusions

The government of Sri Lanka has made major policy changes to the pricing of oil products. It has replaced the old system of fixing the final price of fuel independently of the import price by introducing a formula for fixing product prices that is based on world prices and it proposes to change prices monthly. In the past there have been lags of variable duration between changes in world oil prices and the changes in oil product prices made by the government of Sri Lanka. These lags destabilised government revenue. It has replaced *ad valorem* duties with fixed excise duties, a change that will further stabilise government tax revenue. In the past government revenue from taxes on oil products fluctuated with the price of oil, but under the new system they should be largely independent of the world oil price.

An analysis of Sri Lankan fuel prices and taxes in March 2002 shows that:

- compared to the alternative position of importing refined products at world prices, the CPC refinery is making a loss at an annual rate of at least Rs. 1.8 billion
- the explicit annual tax revenue from oil products is Rs.20.1 billion. After deducting the revenue which would be raised if expenditure on fuel were used for other purposes, the pure fuel tax element is Rs. 19.8 billion and, if the losses of the refinery that is in the public sector are deducted, the budgetary contribution of the fuel taxes is Rs. 18 billion
- the present structure of taxes on petrol, diesel and kerosene does not reflect the environmental externalities, which are higher for diesel and kerosene than for petrol.

Since 1996 there has been a substantial fall in the level of taxes on petrol measured in real terms and a slight erosion of the real tax take per litre of diesel.

Data on fuel consumption and distances driven suggest that there is little if any adulteration of diesel by kerosene at present, though this could become a problem if diesel taxes were to increase significantly relatively to those on kerosene.

The share of petrol in the fuel used for transport has fallen from 30% in 1990 to 18% in 2002. Although the tax on diesel is lower, this has not led to the substitution of diesel for petrol cars, but there has been a rapid expansion of dual-purpose, light duty vehicles using diesel. Whereas car ownership has been growing at 5-6% p.a., and heavy trucks at about 6%, in line with real GDP growth, that of vans and dual purpose vehicles has been growing at 8-9%, and of all vans plus cars at 7%. There therefore appears to have been some substitution of cars by these vehicles.

A series of analyses compare the break-even points for sizes and types of cars and vans in terms of kilometres per year using three sets of assumptions:

- current prices and taxes of fuels and vehicles
- current prices without any taxes on fuels and vehicles
- current prices with a pollution tax on diesel but with no other taxes.

The comparisons indicate whether current taxes are promoting efficient choices of vehicles. Generally, the existing taxes do not distort the choice of type of car, though they do over-encourage the choice of diesel for dual-purpose vehicles (vans). In the absence of taxes on fuel and vehicles or with a pollution tax the same decisions would be made for cars, but probably not for dual-purpose vehicles. Age restrictions on importing cars encourage an inefficient substitution of older diesel-powered dual-purpose vehicles for more heavily taxed younger cars.

5.3. ALTERNATIVE POLICIES FOR FUEL TAXES

5.3.1 Introduction

Table 5.1 in Section 5.2, which gives fuel prices for March 2002, is taken as the base line from which alternative adjustments to the structure of taxes are considered. The main policies to be considered in this chapter are two possible changes in fuel excise duties that eliminate the bias against petrol while preserving government revenue. In the final section of the chapter we consider whether changes in annual license fees or registration charges[12] on cars and dual-purpose diesel vehicles could remove distortions assuming that petrol remains more heavily taxed than diesel.

Current fuel tax policies do not appear to seriously distort the choice of fuel for cars, but at least in some case they encourage the wrong choice for vans and dual-purpose vehicles. It is therefore useful to consider different policies that would narrow the gap between the different fuel prices. The aim here is to estimate the changes needed to make all fuel taxes explicit and to eliminate the gap between the different fuel taxes and prices while leaving government revenues constant. Making all taxes explicit would provide transparency to the fuel tax system. Eliminating the gap between the taxes on the different fuels is justified below in Section 5.6 as a means of roughly reflecting the extra costs of environmental damage and road user costs. In chapter 6 we also argue that higher taxes on petrol can still be justified. They would have the effect of raising additional revenue, and can be considered in the wider context of setting the overall tax and expenditure policy of the GOSL.

Changes in prices caused by changes in taxes will lead to changes in the pattern of demand for vehicles and vehicle use, which will further affect tax revenues. Where the tax changes cause consumers to change their total expenditure on these fuels and vehicles, their expenditure on all other goods, and hence the taxes collected from these other goods, will also change. The fiscal accounting will therefore have to keep track of quantity as well as price changes. We find that these consequential effects are relatively small – of the order of a 2% or so. (The detailed calculations are reported in Section 5.4). That suggests that reasonably accurate estimates can be made in future without taking these additional complications into account.

In the short run, the demand response to changes in fuel prices are likely to be very low as it is not economic to change the type of vehicle or engine very quickly. An elasticity of 0.1 or 0.2 (for fuel use in response to the fuel price) would be a sensible assumption in this case (Note, in this chapter, all elasticities are given as positive numbers, indicating the percentage *fall* in demand for a 1 percent increase in price). In the

[12] The registration charge is paid once whereas the annual licence fee is paid every year. Both policies however can be thought of as equivalent as the increase in the registration charge can be computed as the present value of increase in the future stream of payments of annual licence fees.

medium and longer run, the elasticity would be higher, as users would have a chance to change to different engines (more or less powerful, diesel or petrol), either keeping the existing vehicle or by replacing the vehicle. Higher elasticities of 0.4 and 0.8 were assumed in this case. The appendix summarises the evidence for these elasticity assumptions, which are in line with various estimates of fuel price elasticities in the transport sector.

The figures for consumption of petrol and diesel by the transport sector are estimates for the year 2002, assuming that the average growth rate between 1998 and 2001 would continue for the following year. The following sections describe the various policies considered.

5.3.2 Changes in duties for diesel and petrol

The first policy considered was a change in petrol and diesel excise duties that would keep revenues constant. The excise duty for kerosene was left unchanged. The diesel consumed in power generation was excluded. [13]

The revenues taken into consideration were all the revenues flowing into the GOSL budget from implicit and explicit taxes on fuel plus the revenues that would be collected if consumers increased or decreased their expenditure on other goods and services as a result of a change in their expenditure on fuel.

Implicit taxes in Table 5.5 **(G)** were computed as the difference between the prevailing domestic price **(P)** and the tax inclusive cost Cif to retail **(F)**. These taxes are not identified in the GOSL fiscal accounts and so it has been assumed to be zero in all our policy scenarios. This assumption means that all taxes are explicit in our calculations and some explicit increases may be needed in order to make up for the decrease in implicit taxes if revenues are to be kept constant. The formulaic rates for turnover tax and NSL were left unchanged. Excise duties were changed for petrol and diesel, and made equal in absolute terms.

Although no changes in the excise duty for kerosene were considered, the implicit tax for this fuel was assumed to be zero rather than 0.84 Rs/litre as line **G** in Table 1 shows. With a lower implicit tax the final price would be lower and therefore demand would be higher, unless a zero elasticity of demand were assumed. This is the reason why some of the figures in the column for kerosene change, despite the excise duty not changing at all.

With diesel and petrol duties made equal in absolute terms (Rs/litre) the ratio of the price of petrol to diesel would decrease to 1.04 and incentives to use diesel rather than

[13] The Ceylon Electricity Board (CEB) purchases diesel to run thermal power generators and they do not pay the excise duty.

petrol would be reduced.[14] Table 5.5 shows the results for the different elasticities. It should be noted that implicit taxes were made equal to zero, and although only excise duties were changed (these are expressed in Rupees per litrere), the Turnover Tax also changed because it is dependent on the excise duty.

The final price of petrol goes down in all cases, and the final price of diesel increases. It should be noted that the elasticities assumed, ranging from 0 to 0.8 in the case of petrol, and from 0 to 0.4 in the case of diesel, have little influence on the final prices or the excise duties, and no effect on the price ratios.

Table 5.5: Changes in petrol and diesel duties

	Petrol	Diesel (exc. Pow. Generation)	Kerosene	Totals
P current price Rs/litre	49	26	17.4	
C CPC cost of production (Rs per litre)	19	16.84	16.98	
N NSL (6.5% of pre-excise wholesale price) = 0.065*C	1.24	1.09	1.10	
D Excise duty	24	4	0	
E Turnover Tax (1% of wholesale) = 0.01*(C+D)	0.43	0.21	0.17	
A Total explicit taxes = **N+D+E**	25.67	5.30	1.27	
W Import cost to wholesale	16.51	15.87	15.02	
R Margin from wholesale to retail	0.55	0.26	0.27	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	42.72	21.44	16.57	
G Implicit tax revenue = **P-F**	6.28	4.56	0.83	
Q Consumption Million of litres (excl. Power generation)	369	1940	289	
Total sales of fuel	18.08	50.44	5.03	
Total explicit tax revenues (Rs bill) = **A*Q**	9.5	10.3	0.4	
Total implicit tax revenues (Rs bill) = **G*Q**	2.3	8.9	0.2	
Total tax per litre (implicit and explicit) Rs/litre	31.9	9.9	2.1	
Total tax revenues (implicit and explicit) Rs bill	11.8	19.1	0.6	**31.535**
I CPC profits at international prices (Rs/litre)	-2.5	-1.0	-2.0	
Elasticity	0	0	0	
D new excise duty (Rs /litre)	**12.0885**	**12.0885**	**0**	
E new T/T (Rs/litre)	0.31	0.29	0.17	
N new NSL (Rs/litre)	1.24	1.09	1.10	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	30.69	29.61	16.57	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	13.63	13.47	1.27	
P new price Rs/litre	30.69	29.61	16.57	
Change in quantity	0	0	0	
new quantity (mill litres)	369	1940	289	
new revenues (implicit and explicit) Rs bill	5.03	26.14	0.37	
new retail sales (new price * new quantity) Rs bill	11.33	57.44	4.79	
extra sales on other goods (Rs bill)	6.76	-7.00	0.24	
extra tax revenue from these sales (0.16 * extra sales)	1.08	-1.12	0.04	
Total new revenues from fuels and other sales	6.11	25.02	0.41	**31.535**

[14] As diesel consumption per km is lower than petrol, even at the same price per litre the cost per km of diesel use would be lower.

Elasticity	0.1	0.1	0.1	
D new excise duty (Rs /litre)	**12.1234**	**12.1234**	**0**	
E new T/T (Rs/litre)	0.31	0.29	0.17	
N new NSL (Rs/litre)	1.24	1.09	1.10	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	30.73	29.64	16.57	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	13.67	13.51	1.27	
P new price Rs/litre	30.73	29.64	16.57	
Change in quantity	18	-25	1	
new quantity (mill litres)	387	1915	290	
new revenues (implicit and explicit) Rs bill	5.29	25.86	0.37	
new retail sales (new price * new quantity) Rs bill	11.88	56.76	4.81	
extra sales on other goods (Rs bill)	6.20	-6.32	0.22	
extra tax revenue from these sales (0.16 * extra sales)	0.99	-1.01	0.03	
Total new revenues from fuels and other sales	6.28	24.85	0.40	**31.535**
Elasticity	0.2	0.1	0.1	
D new excise duty (Rs /litre)	**12.0379**	**12.0379**	**0**	
E new T/T (Rs/litre)	0.31	0.29	0.17	
N new NSL (Rs/litre)	1.24	1.09	1.10	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	30.64	29.56	16.57	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	13.58	13.42	1.27	
P new price Rs/litre	30.64	29.56	16.57	
Change in quantity	36	-25	1	
new quantity (mill litres)	405	1915	290	
new revenues (implicit and explicit) Rs bill	5.51	25.71	0.37	
new retail sales (new price * new quantity) Rs bill	12.42	56.61	4.81	
extra sales on other goods (Rs bill)	5.66	-6.17	0.22	
extra tax revenue from these sales (0.16 * extra sales)	0.91	-0.99	0.03	
Total new revenues from fuels and other sales	6.41	24.72	0.40	**31.535**
Elasticity	0.8	0.4	0.2	
D new excise duty (Rs /litre)	**11.7325**	**11.7325**	**0**	
E new T/T (Rs/litre)	0.307325	0.285725	0.1698	
N new NSL (Rs/litre)	1.235	1.0946	1.1037	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	30.33	29.25	16.57	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	13.27	13.11	1.27	
P new price Rs/litre	30.334	29.247	16.568	
Change in quantity	173	-89	3	
New quantity (mill litres)	542	1851	292	
New revenues (implicit and explicit) Rs bill	7.19	24.27	0.37	
New retail sales (new price * new quantity) Rs bill	16.43	54.13	4.84	
Extra sales on other goods (Rs bill)	1.65	-3.69	0.19	
Extra tax revenue from these sales (0.16 * extra sales)	0.26	-0.59	0.03	
Total new revenues from fuels and other sales	7.45	23.68	0.40	**31.535**

In order to actually implement a policy of this type it would be necessary to distinguish between diesel used for power generation and diesel used for transport and other

activities. The excise duty on diesel used for power generation is currently (as in March 2002) zero and would remain unchanged. The policy would work as long as drivers had no access to diesel sold for power generation or were in some way prevented from adulterating diesel with kerosene or other close substitutes. At present this does not seem to be a problem but a policy that substantially increased the price of diesel relative to the price of kerosene could potentially lead to adulteration. In the UK diesel fuel for non-transport use is distinctively coloured to allow its detection in transport use, but this requires inspections and may not be sufficiently effective.

With the current structure of vehicle prices and taxes presented in Table 5.3 (Section 5.2) and with the new prices presented in Table 5.5 of this Section, it would now be cheaper to operate petrol rather than diesel vans. For all new fuel prices presented in Table 5.5 of this Section petrol dominates over any realistic annual distance. Nor would it be cheaper to import a second-hand petrol version and pay the conversion cost of Rs.18,000 (which may be an underestimate) and the additional diesel registration fee of Rs. 350,000. It is clear that changing fuel prices while maintaining the heavy import tax penalty against diesel vehicles would reverse the current demand for diesel vans. As petrol cars are cheaper than diesel cars under the present import tax and fuel price regime, raising the price of diesel will only make petrol versions even more attractive. Diesel cars in any case only represent 10% of total cars, and their presence is probably explained by concessional imports in the past, not the current tax regime.

5.3.3 Changes in duties for diesel, petrol and kerosene

The second policy considered is one in which taxes on all three fuels – petrol, transport diesel and kerosene – are equalised, keeping revenue constant. This policy addresses the possible concern that if diesel is increased in price and kerosene is left untaxed, then the incentive to adulterate diesel with kerosene increases, leading to fiscal loss. The results are presented below in Table 5.6. Again the revenues to be held constant are all those received by GOSL from whatever source, i.e. both explicit and implicit taxes, and from sales of other goods and services.

The price of kerosene with this type of policy would be substantially increased (by 58%). The impacts of this policy on household's welfare are analysed in Section 5.4. As pointed out in Section 5.2 the main increase in diesel consumption was caused by an increase in the absolute and relative number of dual-purpose vehicles. If private motorists are to be discouraged from substituting diesel vans for petrol cars, the import regime and possibly the various import taxes and registration charges will need to be adjusted. Changing fuel prices alone is unlikely to have much effect on the relative consumption of diesel and petrol.

Table 5.6: Changes in diesel, petrol and kerosene duties

	Petrol	Diesel (exc. Pow. generation)	Kerosene	Total
P current price Rs/litre	49	26	17.4	
C CPC cost of production (Rs per litre)	19	16.84	16.98	
N NSL (6.5% of pre-excise wholesale price) = 0.065*C	1.235	1.095	1.104	
D Excise duty	24	4	0	
E Turnover Tax (1% of wholesale) = 0.01*(C+D)	0.43	0.21	0.17	
A Total explicit taxes = **N+D+E**	25.67	5.30	1.27	
W Import cost to wholesale	16.51	15.87	15.02	
R Margin from wholesale to retail	0.55	0.26	0.27	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	42.72	21.44	16.57	
G Implicit tax revenue = **P-F**	6.28	4.56	0.83	
Q Consumption Million of litres (excl. Power generation)	369	1940	289	
Total sales of fuel	18.08	50.44	5.03	
Total explicit tax revenues (Rs bill) = **A*Q**	9.5	10.3	0.4	
Total implicit tax revenues (Rs bill) = **G*Q**	2.3	8.9	0.2	
Total tax per litre (implicit and explicit) Rs/litre	31.9	9.9	2.1	
Total tax revenues (implicit and explicit) Rs bill	11.8	19.1	0.6	**31.535**
I CPC profits at international prices (Rs/litre)	-2.5	-1.0	-2.0	
Elasticity	0	0	0	
D new excise duty (Rs /litre)	**10.7435**	**10.7435**	**10.7435**	
E new T/T (Rs/litre)	0.30	0.28	0.28	
N new NSL (Rs/litre)	1.24	1.09	1.10	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	29.33	28.25	27.42	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	12.28	12.11	12.12	
P new price Rs/litre	29.33	28.25	27.42	
Change in quantity	0	0	0	
new quantity (mill litres)	369	1940	289	
new revenues (implicit and explicit) Rs bill	4.53	23.50	3.50	31.53
new retail sales (new price * new quantity) Rs bill	10.82	54.80	7.92	73.55
extra sales on other goods (Rs bill)	7.26	-4.36	-2.90	105.08
extra tax revenue from these sales (0.16 * extra sales)	1.16	-0.70	-0.46	0.00
Total new revenues from fuels and other sales	5.69	22.80	3.04	**31.535**

Elasticity	0.1	0.1	0.1	
D new excise duty (Rs /litre)	**10.7782**	**10.7782**	**10.7782**	
E new T/T (Rs/litre)	0.30	0.28	0.28	
N new NSL (Rs/litre)	1.24	1.09	1.10	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	29.37	28.28	27.45	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	12.31	12.15	12.16	
P new price Rs/litre	29.37	28.28	27.45	
Change in quantity	19	-16	-13	
new quantity (mill litres)	388	1924	276	
new revenues (implicit and explicit) Rs bill	4.78	23.37	3.36	31.51
new retail sales (new price * new quantity) Rs bill	11.41	54.41	7.58	73.40
extra sales on other goods (Rs bill)	6.67	-3.97	-2.55	104.91
extra tax revenue from these sales (0.16 * extra sales)	1.07	-0.64	-0.41	0.02
Total new revenues from fuels and other sales	5.85	22.74	2.95	**31.535**
Elasticity	0.2	0.1	0.1	
D new excise duty (Rs /litre)	**10.7053**	**10.7053**	**10.7053**	
E new T/T (Rs/litre)	0.30	0.28	0.28	
N new NSL (Rs/litre)	1.24	1.09	1.10	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	29.30	28.21	27.38	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	12.24	12.08	12.09	
P new price Rs/litre	29.30	28.21	27.38	
Change in quantity	40	-16	-13	
new quantity (mill litres)	409	1924	276	
new revenues (implicit and explicit) Rs bill	5.00	23.24	3.34	31.58
new retail sales (new price * new quantity) Rs bill	11.98	54.28	7.56	73.83
extra sales on other goods (Rs bill)	6.10	-3.84	-2.53	105.40
extra tax revenue from these sales (0.16 * extra sales)	0.98	-0.61	-0.41	-0.04
Total new revenues from fuels and other sales	5.98	22.62	2.93	**31.535**
Elasticity	0.8	0.4	0.2	
D new excise duty (Rs /litre)	**10.3643**	**10.3643**	**10.3643**	
E new T/T (Rs/litre)	0.293643	0.272043	0.273443	
N new NSL (Rs/litre)	1.235	1.0946	1.1037	
F Tax inclusive cost cif to retail = **W+N+D+E+R**	28.95	27.86	27.04	
G new implicit tax (Rs/litre) = **P-F**	0	0	0	
new tax per litre (implicit and explicit) Rs/litre	11.89	11.73	11.74	
P new price Rs/litre	28.952	27.865	27.035	
Change in quantity	193	-53	-24	
new quantity (mill litres)	562	1887	265	
new revenues (implicit and explicit) Rs bill	6.69	22.14	3.11	31.93
new retail sales (new price * new quantity) Rs bill	16.27	52.58	7.15	76.01
extra sales on other goods (Rs bill)	1.81	-2.14	-2.13	107.94
extra tax revenue from these sales (0.16 * extra sales)	0.29	-0.34	-0.34	-0.39
Total new revenues from fuels and other sales	6.97	21.79	2.77	**31.535**

5.3.4 Changes in vehicle taxes

Table 5.3 shows that the current higher tax on petrol together with the structure of prices and taxes for vehicles encourages the substitution of older diesel dual-purpose vehicles for cars. Section 5.2 also showed that equalising fuel taxes and eliminating import tariffs would encourage the purchase of petrol rather than diesel vans, but unless the age discrimination against cars was removed, would still encourage some consumers to purchase dual-purpose vehicles rather than cars. If the current system of import tariffs were kept, while fuel taxes were equalised, the bias in favour of petrol choices would be increased. If, however, the GOSL wishes to retain the current differential tax on petrol, and does not change the import rules, then the present distortions are likely to continue. They could in principle be reversed by further increasing either the import duty or registration charge on the diesel dual-purpose vehicles or by increasing the annual license fee. Note this policy could actually worsen pollution if imports are reduced and the old vehicles already in Sri Lanka are used for longer. In Section 5.2 we showed that if cars paid the current import duties it would normally be cheaper to choose petrol-engined cars than diesel. Some diesel vehicles may be imported as they enjoy concessions. If it were felt that these concessionary imports should also be guided to make petrol choices, then one solution would be to impose a higher annual license fee on diesel vehicles, reflecting the difference of tax receipts between a typical car from the fuel taxes. If we assume that the number of litres consumed per year is the same whether petrol or diesel (and diesel cars normally drive further but have better fuel efficiency) and if we take the annual consumption for a medium car as 700 litres, then with present taxes the required differential of the annual fee would be 20 Rs/litre times 700 litres, or 14,000 Rs/year. At present the differential is only 1,000 Rs, so this would represent a significant increase. For a small car using 600 litres/year, the increase would be 12,000 Rs/yr. It seems unlikely that an increase of this amount would be acceptable, and in any case it would be better to address the source of the problem, namely concessionary imports.

5.3.5 Changes in vehicle and fuel taxes

If the price of petrol were kept around 25% above the price of diesel, and diesel and kerosene had the same excise duty, the final prices for petrol and diesel would be 34 and 27 Rs per litre respectively. The differential would then be only 7 Rs per litre, which assuming (again) consumption for a medium car as 700 litres, would require an increase in the annual fee of 4,900 Rs/year. If this were capitalised into the registration and/or extra import duty, it would amount to perhaps 35,000 Rs. At present the differential import tax on cars is closer to 1,000,000 Rs, so there is little case for a differential license fee as well. Indeed, that would be an argument for reducing the disparity between the import taxes on diesel vs petrol cars. In the case of vans the

differential import tax is lower, but even here the difference for a Vennett is 160,000 Rs, and for a Townace closer to 300,000 Rs. If the petrol tax differential were 7 Rs per litre, and fuel consumption as high as 2,000 litres/year, the capitalised value would still only be 70,000 Rs. The conclusion is that if fuel taxes are adjusted to narrow the differential, it would be possible to reduce the current discrimination against diesel-engined imports that arise because of the higher import taxes.

Finally, a third option might be to change import duties on different vehicle types to induce efficient choices, given the chosen fuel tax differential. One solution would be to set import duties at the same *ad valorem* rate for all relevant vehicles (certainly all those that are substitutes for non-commercial use), and set the initial registration charge (paid at the moment the vehicle is put on the road) to induce the right choice fuel type. This would be quite complex as the difference in price between the two versions varies widely. Thus for the cars considered in Section 5.2, equalising the effective tariff rate at 90% would still tax diesel versions more heavily than the loss in annual excess petrol tax at 7 Rs per litre, as it would for the Townace van but not for the Vennett van.

5.3.6 Conclusions

A sensitivity analysis of changes to duties on diesel and petrol shows that revenue-neutral changes to even out the rates of duty would have the desired effects on the choice of fuel for newly imported vehicles. This would gradually alter the balance of fuel use of the entire vehicle stock, but only over a relatively long period.

The main reason for the substitution of cars by dual-purpose vehicles appears to be the more favourable import regime for these vehicles. Imported cars cannot be older than 3 years, while vans can be up to 5 years old, and hence considerably cheaper. As the import duties are *ad valorem*, cheaper vehicles, particularly vans and dual purpose vehicles, are unduly encouraged, despite the higher rates of import duty on diesel vehicles. This can be addressed by equalising the maximum age for vehicles. It would then be possible to reduce at least some of the differential import tax between petrol and diesel.

5.4. IMPACT OF EACH POLICY ON HOUSEHOLD'S WELFARE

5.4.1 Introduction

The objective of this chapter is to examine the impact of fuel price changes on the welfare of households in different parts of the income distribution in Sri Lanka. The chapter utilises the 1994 Input Output Table and data from the 1995/96 Household Budget Survey for Sri Lanka. The chapter is divided into a number of sections. The next section describes briefly the data and methodology used. It refers to more detailed descriptions in the appendices. The next section describes the industrial sectors with the highest usage of fuels. Then we analyse fuel consumption by household across the income distribution. We consider separately fuels that are directly consumed by households and fuels that are indirectly consumed as inputs into other goods and services. We examine the effect on welfare of changes in the price of fuels, looking at petrol, diesel and kerosene separately. The main analysis, which concerns alternative revenue neutral reforms of petrol, diesel and kerosene prices, follows. The last section concludes.

5.4.2 Data and Methodology

The question we are considering is how do changes in fuel tax policy affect households' expenditures in Sri-Lanka. If the price of a fuel changes, then households will be affected in two ways:

a) Firstly, the prices of the fuels that households consume will change.
b) Secondly, the prices of the fuels that are consumed as inputs into the goods and services that households consume will change. If the firms and businesses pass on fuel price changes to the consumers of their goods and services, then the prices of the goods and services consumed by households will also change.

Effect on Industry

Changes to fuel prices affect firms in a similar way to households. Firms consume fuels in the production of goods and services (direct inputs) and, in addition, the other inputs they use may have fuel inputs (indirect inputs). Therefore each good and service purchased by a household will itself have direct and indirect fuel inputs.

In order to model the transmission of price changes through the economy to the household sector, we use the Input-Output Table for 1994 (prepared by the Department of National Planning, Sri Lanka). Leontief (1951) was the first to develop the methodology used in input-output analysis. Similar published analyses include

O'Donoghue (1997) for Ireland, Gay and Proops (1993) for the UK and Casler and Rafiqui (1993) for the USA.

An input-output table contains information about sectors of an economy, mapping the flows of inputs from one sector to another or to final demand (that consumed by households or exported, etc.). Output in each sector has two possible uses; it can be used for final demand or as an intermediate input for other sectors. In an n sector economy, final demand for sector i's produce is denoted by d_i and the output of sector i by x_i . Intermediate input from sector i into sector j is defined as $a_{ij}\ x_j$, where a_{ij} , the input coefficients, are fixed in value. In other words, a_{ij} is the quantity of commodity i that is required as an input to produce a unit of output j. Output can therefore be seen as a sum of intermediate inputs and final demand, as follows:

$$x_i = \Sigma_j\ a_{ij}.x_j + d_i \qquad (1)$$

or in matrix terminology:

$$x = A.x + d \qquad (2)$$

Combining the output coefficients to produce an (I-A) *technology matrix* and inverting, the *Leontief inverse matrix,* $(I-A)^{-1}$ is produced, which gives the direct and indirect inter industry requirements for the economy:

$$x = (I-A)^{-1}.d \qquad (3)$$

Equation 3 can be expanded to produce the following

$$x = d + Ad + A^2d + A^3d + A^4d + ... \qquad (4)$$

As A is a non-negative matrix with all elements less than 1, A^m approaches the null matrix as m gets larger, enabling us to get a good approximation to the inverse matrix. Equation 5, thus expands output per sector into its components of final demand d; Ad, the inputs needed to produce d; A^2d, the inputs required to produce Ad, etc. to produce the number of units of each output used in the production of a unit of final demand for each good.

If tax t is applied and is passed on in its entirety to consumers, then the tax on goods consumed in final demand is td, the tax on the inputs to these goods is tAd, the tax on inputs to these is tA^2d and so on. Combining, total tax is

$$td + tAd + tA^2d + tA^3d + tA^4d + ... = t(I-A)^{-1}.d \qquad (5)$$

A number of adjustments had to be made to the input-output analyses for our purposes.

First, the input-output (IO) table contains information on only one fuel sector, petroleum & coal products. We need to decompose this component of the IO table into its constituent parts because we want to focus on the differential effects of price changes of individual fuels such as petrol, diesel, kerosene and other fuels. This has been done utilising assumptions provided by an official in Sri Lanka and outlined in Appendix E.

Second, the IO table relates to the economy in 1994 prices. We wish to consider the situation in 2002. While producing a new IO table is beyond a short project such as this, we would like to incorporate the effects of the changes, since 1994, in the prices of fuels, relative to prices in the rest of the economy. (See appendix G for a further description)

A Leontief Inverse Matrix has been produced for Sri Lanka, $(I-A)^{-1}$ utilising the assumptions described here and is contained in the tables in appendix H. This matrix is used to find the effects (both direct and indirect) of a change in the price of fuel on each sector of the economy.

Effect on Households

Once the direct and indirect price changes in the economy as a whole are known, we can then consider the effect on households. The direct and indirect price changes per industrial sector give us the price changes that households will observe. In order to quantify the effects on households, we need a source of data that contains household expenditures. For this we utilise the 1995/96 Sri Lanka Household Budget Survey.

Again, as in the case of the input-output table, we need to make some adjustments to the data. Firstly, the data is out of date. The growth rate of expenditure on fuels over the period has been different to that for expenditure on other goods. This is due to changes in relative prices (prices of petrol and kerosene have grown more slowly than average and diesel more quickly) and the volumes consumed. Most sectors are assumed to have grown at the nominal rate of GNP growth per capita. Nominal GNP per capita in 2002 was approximately 215% that in 1995, while consumption per capita of kerosene, petrol and diesel were 169%, 152% and 363% of the expenditure levels in 1995. Fuel consumption growth over the period was primarily driven by the growth in auto diesel fuel. Petrol and kerosene consumption grew at a lower rate than the growth rate of the economy.

The second adjustment that is made relates to the fact that motor fuels are not disaggregated into diesel and petrol. We assume that in 1995, 13% of total motor fuel consumption went on diesel, with the remaining 87% on petrol.

Microsimulation Model

In order to simulate the effect of fuel price changes on Sri-Lanka households, we have constructed a Microsimulation model for Sri Lanka, *Sri Lanka Inequality and*

Environmental eValuation Engine (SLIEVE[15]). This model is programmed in the C++ programming language.

The model simulates the distributional impact of price related policy changes in Sri Lanka and takes as input the following information:

- 1994 Sri Lanka Input-Output Model (IO)
- 1995/96 Sri Lanka Household Budget Survey (IndDataHBS)
- Transformation Matrix to convert IO sectors to HBS expenditure variables (IOHBSTrans).
- Price elasticities (BehavResp)
- A set of Price changes or policy reforms (PriceChange)

The model comprises a set of matrices that are manipulated to carry out the analyses we are interested in.

In order to measure the impact of policy reforms, we simulate the effect of price changes. The model allows the price of any IO Sector to be altered. The model applies the price change to the input-output Leontief matrix, so that we get the net price change in each sector. The sector headings in IO table are different to the HBS, so we then apply the IO price changes to the IO HBS Transformation matrix, to get the net price change in each expenditure category in the HBS.

If the prices of goods change, then households will alter their consumption behaviour. Although the model allows for an 11 sector demand system (with own and cross-price elasticities to be specified for each of 11 aggregate sectors) to be included, data limitations mean that such a complicated system cannot be implemented. We therefore make assumptions about potential price elasticities for Sri-Lanka. As we shall see later, we vary our assumptions about the price elasticity of demand for fuels, holding the price elasticity for other goods at –1. In other words the price effect of a 1% increase in the price of another good will result a 1% fall in consumption of that good. We assume independence in consumption of different goods (so that all cross-price elasticities are 0).

We assume that total household expenditure remains constant before and after the price change. Therefore, if the price of a good increases, consumption of that good (assuming a negative elasticity) will fall. If consumption of the good falls by less/more than the value of the price change, then the consumption of other goods must also change. The model firstly evaluates total expenditure applying the price change and elasticities specified. If the resulting total expenditure is higher than that observed before the price change, then expenditure on each good is scaled back so as to leave total expenditure unchanged.

Changes in welfare are measured by the changes in the volume of total consumption.

[15] Slieve is the Irish for Hill.

5.4.3 Industry Consumption of Fuels

In this section we describe the total consumption of petrol, diesel, kerosene and other fuels by industrial sector. The measures cover both direct and indirect amounts of fuel consumption and so include both the fuels consumed directly by each sector, plus also the fuels consumed in the production of the other inputs used in the sector. Table 5.7 reports the total inputs of the fuels as a percentage of final demand for industrial sectors. Assuming that price changes are passed on in their entirety to consumers, these values are equivalent to the impact of a price increase of 100% in the particular fuel on the price of the output of the sector. The sectors with the highest fuel consumption are the transport sectors, electricity, baking, cement and fishing.

Table 5.7: Direct and Indirect Industry Expenditure on Petrol, Diesel and Kerosene (as a % of Value of Final Demand) at 2002 prices

	Petrol	Diesel	Kerosene	Other	Total
Railway transport	5.7	32.1	0.0	1.0	38.8
Road passenger transport	3.4	19.2	0.0	0.5	23.1
Electricity	0.1	0.5	0.0	7.7	8.3
Bread	0.8	6.0	0.7	0.2	7.7
Cement & cement products	0.1	1.3	0.0	4.6	6.0
Fishing	0.4	3.7	1.1	0.1	5.3
Non-profit govt. inst.	2.0	2.6	0.0	0.3	4.9
Ceramics, glass & glass products	0.1	0.9	0.0	3.2	4.2
Rubber products	0.5	2.9	0.0	0.5	3.9
Hotels & restaurants	1.0	1.8	0.1	0.4	3.3
Tea processing	0.4	2.5	0.0	0.3	3.2
Rubber processing	0.4	2.4	0.0	0.2	3.0
Paddy growing	0.2	1.9	0.6	0.1	2.8
Tourism	0.7	1.4	0.0	0.3	2.4
Construction	0.2	1.1	0.0	0.7	2.0
Wood products	0.3	1.4	0.0	0.2	1.9
Textiles	0.2	1.4	0.1	0.2	1.9
Milling	0.1	1.3	0.3	0.1	1.8
Ngo	0.5	0.8	0.0	0.5	1.8
Govt admin & defence	0.7	1.0	0.0	0.2	1.9
Other services	0.6	0.9	0.0	0.3	1.8
Paper & paper products	0.2	1.3	0.0	0.2	1.7
Pharmaceuticals	0.1	0.4	0.5	0.5	1.5
Transport equipment	0.2	1.0	0.0	0.2	1.4
Structural & clay products	0.1	0.4	0.1	0.8	1.4
Bottled fruit	0.1	0.8	0.1	0.3	1.3
Light engineering	0.2	1.0	0.0	0.1	1.3
Beverages	0.1	0.8	0.1	0.3	1.3
Other bakery products	0.1	0.8	0.1	0.2	1.2
Confectionery	0.1	0.9	0.1	0.1	1.2

Oil & fats	0.2	0.9	0.0	0.1	1.2
Trade & other transport	0.2	0.9	0.0	0.1	1.2
Leather & leather products	0.1	0.8	0.0	0.1	1.0
Dairy products	0.1	0.7	0.1	0.1	1.0
Coconut fiber & yam	0.1	0.7	0.0	0.0	0.8
Health services	0.1	0.3	0.1	0.4	0.9
Other processed foods	0.1	0.6	0.1	0.2	1.0
Education services	0.3	0.5	0.0	0.2	1.0
Machinery & equipment	0.1	0.6	0.0	0.1	0.8
Desiccated coconut	0.1	0.5	0.0	0.1	0.7
Mining & quarrying	0.1	0.2	0.4	0.1	0.8
Toilet preparations	0.1	0.4	0.1	0.2	0.8
Logging & firewood	0.1	0.5	0.1	0.0	0.7
Basic metals & rolling	0.1	0.3	0.0	0.3	0.7
Communication	0.1	0.4	0.0	0.2	0.7
Chemicals & chemical product	0.0	0.2	0.2	0.3	0.7
Alcoholic beverages	0.1	0.4	0.0	0.1	0.6
Electrical appliances	0.1	0.4	0.0	0.1	0.6
Printing & publishing	0.1	0.4	0.0	0.1	0.6
Other manufactures	0.1	0.4	0.0	0.1	0.6
Livestock	0.0	0.3	0.0	0.2	0.5
Other agriculture	0.0	0.3	0.1	0.0	0.4
Garments	0.1	0.3	0.0	0.1	0.5
Fertilizer & agro-chemicals	0.1	0.3	0.0	0.1	0.5
Coconut growing	0.1	0.3	0.0	0.0	0.4
Insurance	0.1	0.2	0.0	0.1	0.4
Banking	0.0	0.2	0.0	0.1	0.3
Tobacco manufacturing	0.0	0.1	0.0	0.0	0.1
Tea growing	0.0	0.1	0.0	0.0	0.1
Ownership of dwellings	0.0	0.0	0.0	0.1	0.1
Rubber growing	0.0	0.1	0.0	0.0	0.1
Forestry	0.0	0.0	0.0	0.0	0.0

Source: SLIEVE

Table 5.7 shows that unless railway transport is exempted from the diesel excise duty, costs will rise by 32% of the price increase, so a 25% increase in the price of diesel would raise rail costs by 8%. The reason for the large impact is that railways are heavily subsidised, so that fuel price increases lead to large increases in costs as a fraction of the (under-priced) revenue. If the Government absorbs the diesel excise duty rise by increasing rail subsidies, the net impact on the budget will be the same as if the railways were exempt from the excise (increase).

5.4.4 Household Consumption of Fuels

Policy changes that affect prices will affect households that consume fuels. In this section we report the simulated distribution of fuel consumption in 2002. Table 5.8

reports the distribution of direct petrol, diesel and kerosene expenditure by household consumption decile[16]. It does not consider fuel expenditures used as an input into other goods and services purchased. Total expenditure on each fuel is reported as a percentage of total expenditure for the decile. We see that petrol and diesel consumption is highly concentrated at the top of the distribution. While 0.01% of expenditure is spent on petrol by the bottom decile, over 2% is spent by the top decile. A similar distribution applies to diesel. Kerosene expenditure meanwhile exhibits the opposite pattern, with the bottom decile spending nearly 1.5% of all their total expenditure on kerosene, while the top decile spends less than 0.1%. Motor fuel is a luxury and so is more focused at the top of the distribution, while heating/cooking fuels, such as kerosene, are more focused on the bottom of the distribution. Therefore changes in the price of petrol and diesel will affect the top of the distribution more, while, changes in the price of kerosene will affect the bottom of the distribution more.

Table 5.8: Direct Household Expenditure on Fuels (as a % of value of total Consumption) by Consumption Decile, 2002 prices

Decile	Petrol	Diesel	Kerosene	Total
1	0.01	0.00	1.46	1.47
2	0.03	0.01	1.13	1.17
3	0.06	0.02	1.00	1.08
4	0.10	0.03	0.87	1
5	0.12	0.04	0.77	0.93
6	0.19	0.07	0.63	0.89
7	0.40	0.14	0.47	1.01
8	0.46	0.16	0.35	0.97
9	0.90	0.31	0.21	1.42
10	2.18	0.76	0.07	3.01
Total	0.88	0.31	0.45	1.64

Source: SLIEVE

However, as pointed out above, a change in the price of a fuel will not only affect the prices of fuels consumed by households but also the prices of other goods consumed because of the impact on the fuel inputs of these goods. Table 5.9 reports the distribution of direct and indirect petrol, diesel and kerosene expenditure by household expenditure decile. Total expenditure on each fuel is reported as a percentage of total expenditure for the decile. Relatively little petrol and kerosene are used in industrial production, so the patterns of consumption of both of these are relatively similar to the pattern in Table 5.8, with petrol consumption being targeted at the top of the

[16] To account for economies of scale, consumption has been equivalised using the number of persons in the household to the power of 0.7.

distribution and kerosene at the bottom. The distribution of direct and indirect diesel consumption is much flatter than before. While less than 0.01% of the bottom decile's *direct* expenditure went on diesel, the percentage of direct and indirect consumption of diesel is much higher at 1.34% because diesel is used in the production of goods and services such as public transport. The top of the distribution still has a higher consumption at 2.08% compared to 0.76% before. The conclusion is similar to before. Price changes that relate to diesel or petrol will affect the rich more and kerosene less. However, we must note that even when the effects of indirect inputs are included, the maximum fuel consumption (petrol, diesel and kerosene) is 4.7% of total expenditure for the top decile, so increases in the price of fuel have a limited impact on the welfare of households.

Table 5.9: Direct and Indirect Household Expenditure on Fuels (as a % of total Consumption Expenditure) by Consumption Decile, 2002 prices

Decile	Petrol	Diesel	Kerosene	Total
1	0.23	1.34	1.64	3.21
2	0.25	1.41	1.33	2.99
3	0.27	1.41	1.19	2.87
4	0.32	1.43	1.07	2.82
5	0.34	1.46	0.96	2.76
6	0.43	1.53	0.82	2.78
7	0.65	1.61	0.65	2.91
8	0.72	1.66	0.52	2.90
9	1.16	1.80	0.37	3.33
10	2.44	2.08	0.19	4.71
Total	1.12	1.72	0.62	3.46

Source: SLIEVE

5.4.5 Impact of Price Changes

In this section we consider the effect of price changes of the different fuels. We consider separately the welfare impact of changing the price of petrol, diesel and kerosene. In parallel we consider the impact of different assumptions about the elasticity used. Results are reported in appendix H Tables H1 – H12 describe the welfare effects of price changes to Petrol, Diesel and Kerosene respectively as measured by the percentage change in volume consumption. Each sub-table makes a separate assumption about the price elasticity of demand for each fuel. The elasticity applies only to fuel whose price has changed. All other goods have an elasticity of –1 and it is assumed that total expenditure remains constant before and after the price change. The results indicate that the welfare impacts are linear in the proportional price change, and so it is possible to summarise the results of those tables in the form of a ready reckoner which is shown in Table 5.10.

The entries in Table 5.10 show the impact on welfare, measured as a percentage of the value of initial expenditure, of a 100% change in the price of the fuel. Thus to compute the impact of a 10% increase in the price of petrol when the elasticity is –0.5, multiply the elements of the column under Petrol, elasticity = -0.5, by 10%. For the 7th decile the relevant entry in table 4 is -0.447, so the impact on that decile is -0.0447, or a decrease in welfare of 0.04 of 1%. Furthermore, the results are additive. Thus the welfare impact of a 10% decrease in petrol price when the elasticity is –0.8, a 50% increase in diesel when the elasticity is –0.2, and a 30% increase in kerosene when the elasticity is –0.5 for the first decile is (10% of –0.227) + (50% of –1.34) + (30% of –0.91) = -0.92 of 1%.

Table 5.10: Percentage change in welfare in response to a 100% change in fuel price

Fuel:	Petrol			
Elasticity:	-0.1	-0.2	-0.5	-0.8
Decile				
1	-0.222	-0.222	-0.225	-0.227
2	-0.224	-0.227	-0.236	-0.244
3	-0.223	-0.229	-0.246	-0.262
4	-0.231	-0.240	-0.269	-0.298
5	-0.237	-0.249	-0.284	-0.320
6	-0.256	-0.275	-0.333	-0.391
7	-0.285	-0.325	-0.447	-0.568
8	-0.302	-0.348	-0.486	-0.625
9	-0.352	-0.441	-0.711	-0.980
10	-0.471	-0.690	-1.346	-2.001
Total	-0.332	-0.420	-0.683	-0.947
Decile	Diesel			
1	-1.34	-1.34	-1.34	-1.34
2	-1.40	-1.40	-1.40	-1.41
3	-1.39	-1.39	-1.40	-1.40
4	-1.39	-1.40	-1.41	-1.42
5	-1.42	-1.42	-1.44	-1.45
6	-1.45	-1.46	-1.49	-1.51
7	-1.46	-1.47	-1.52	-1.58
8	-1.48	-1.50	-1.56	-1.62
9	-1.47	-1.50	-1.62	-1.73
10	-1.25	-1.35	-1.62	-1.89
Total	-1.39	-1.42	-1.53	-1.65

Decile	Kerosene			
1	-0.33	-0.48	-0.91	-1.35
2	-0.31	-0.42	-0.76	-1.10
3	-0.29	-0.39	-0.69	-0.99
4	-0.28	-0.37	-0.63	-0.89
5	-0.27	-0.35	-0.58	-0.81
6	-0.25	-0.31	-0.50	-0.70
7	-0.23	-0.28	-0.42	-0.56
8	-0.21	-0.24	-0.35	-0.45
9	-0.18	-0.20	-0.27	-0.33
10	-0.12	-0.13	-0.15	-0.18
Total	-0.21	-0.25	-0.39	-0.53

Source: Appendix H, Tables H1 – H12

We consider petrol first. We see that for price decreases welfare increases and vice versa for price increases. The effect on the top decile is over twice that for the bottom decile. The reason is that 95% of petrol consumption in the bottom decile is indirect (used in the production of goods and services), while for the top of the distribution only 10% of consumption is indirect. As a result, a price change for petrol will affect welfare through the change in the price of other goods and services more for poor households than for rich households. The direct effect on petrol consumption will be more important in determining welfare changes for richer households. Because other goods and services have an elasticity of –1, proportionally more of poor households' consumption has a higher elasticity and so changes in the assumption regarding the elasticity of petrol will have little effect on these. Therefore regardless of the assumption about the price elasticity of demand for petrol, the welfare change for the bottom decile is similar. However, for the top of the distribution, we see a greater impact of the elasticity assumption. The higher the assumed elasticity the more the rich are affected and so the greater the differential effect of the price change on the rich relative to the poor.

Turning to diesel, price changes have considerably larger effects than for petrol, reflecting its larger total budget share shown in Table 3. The direct and indirect consumption of diesel is much more even across the distribution than petrol and so the effect on distribution is much less noticeable. While direct consumption of diesel is concentrated at the top of the distribution, the indirect effect is more important for each decile because diesel is an important input to many goods and services. The indirect effect is most important at the bottom of the distribution and progressively less important higher in the distribution. When a price elasticity of demand for diesel of –0.1 is assumed, the bottom and the top of the distribution are those least affected. However, as the elasticity increases the fact that the top of the distribution has more direct consumption of diesel begins to make a larger difference. For an elasticity of –

0.8, the impact of the price change is progressive, with the top decile having a welfare change 40% higher than the bottom decile.

The distributional effect of price changes on kerosene is the reverse of that of petrol. Kerosene is primarily consumed directly by households and with the poor having a disproportionate budget share. As a result the indirect effect is small and the effect is concentrated amongst the poor. The greater the price elasticity of demand for kerosene, the greater this differential effect.

We can therefore conclude that price changes to petrol will tend to have a greater effect on the top of the distribution, while changes in the price of kerosene will have a greater effect at the bottom and changes to diesel will be more evenly spread. Because diesel is relatively more important than the other fuels because of its indirect impact, it will tend to dominate the overall effect.

5.4.6 Policy Reforms

In this section, we consider the distributional impacts on households in Sri Lanka of a number of different policy changes. These correspond to the policies described in Section 5.3.

Table 5.11 details the principle policy changes. The first set of policies considers revenue neutral reforms of petrol and diesel duties (with a minor kerosene reform). The second set of policy reforms is revenue neutral, involving changes to the duties on petrol, diesel and kerosene. The last set of reforms considers changes to the duties on petrol and diesel and to vehicle taxation. The sensitivity of the results to differences in price elasticities is analysed.[17] It is not possible to identify the effect of changes in vehicle taxation because we do not have data on vehicle ownership in the household budget survey data set, Therefore, we only examine the effect of the changes in the fuel duties.

[17] It must be noted that revenue neutrality occurs over the economy as a whole and not simply in the household sector that is modelled here.

Table 5.11: Price Related Policy Reforms

	Proportional Price Change			Elasticity		
	Petrol	Diesel	Kerosene	Petrol	Diesel	Kerosene
Original Price	49	26	17.4			
Reform						
Petrol/Diesel/Kerosene 1						
1	-0.374	0.139	-0.048	0.000	0.000	0.000
2	-0.373	0.140	-0.048	0.100	0.100	0.100
3	-0.375	0.137	-0.048	0.200	0.100	0.100
4	-0.381	0.125	-0.048	0.800	0.400	0.200
Petrol/Diesel/Kerosene 2						
5	-0.401	0.086	0.576	0.000	0.000	0.000
6	-0.401	0.088	0.578	0.100	0.100	0.100
7	-0.402	0.085	0.574	0.200	0.100	0.100
8	-0.409	0.072	0.554	0.800	0.400	0.200
Petrol/Diesel/Vehicle Tax						
9	-0.204	0.192		0.1	0.1	
10	-0.306	0.038		0.1	0.1	
11	-0.372	0.000		0.1	0.1	
12	0.000	0.700		0.1	0.1	

Policy Reform: Petrol, Diesel and Kerosene 1

Table 5.12 describes the percentage change in welfare as measured by the volume of total consumption (new volume as a % of previous volume as measured by previous price). The policy changes considered relate to petrol and diesel with a minor change in the price of kerosene. For the first two policy reforms, we see that the results are broadly similar, with all deciles having a small fall in welfare of the order of a quarter of a percentage point. The top decile has the lowest fall, with the bottom decile having the next lowest fall. The fall in welfare for other deciles is quite similar. In reforms 3 and 4 the results are regressive with the welfare loss decreasing as one goes up the distribution, with in fact the top two deciles of the distribution having a net gain. This is due to the fact that with the assumption of higher elasticities, the effect of a petrol price decrease is a rise in consumption of petrol for consumers of petrol, who tend to be at the top of the distribution. With lower elasticities, consumption increases were more evenly spread across the distribution.

Table 5.12: Welfare Change (% Change in pre-price consumption) by Consumption Decile for Petrol, Diesel and Kerosene Reforms (Set 1)

Reform	1	2	3	4
Elasticity	0/0/0	0.1/0.1/0.1	0.2/0.1/0.1	0.8/0.4/0.2
Price Change (Petrol/Diesel/ Kerosene)	-0.374/0.139/ -0.048	-0.373/0.140/ -0.048	-0.375/0.137/ -0.048	-0.381/0.125/ -0.048
Decile				
1	-0.09	-0.09	-0.08	-0.06
2	-0.10	-0.10	-0.09	-0.06
3	-0.10	-0.10	-0.09	-0.06
4	-0.10	-0.10	-0.09	-0.05
5	-0.10	-0.10	-0.09	-0.05
6	-0.10	-0.10	-0.09	-0.04
7	-0.10	-0.09	-0.08	0.01
8	-0.10	-0.09	-0.07	0.02
9	-0.09	-0.08	-0.05	0.10
10	-0.07	-0.03	0.04	0.38
Total	-0.09	-0.08	-0.04	0.11

Source: SLIEVE

Note: Elasticity and Price Change are given in the order Petrol/Diesel/Kerosene

Policy Reform: Petrol, Diesel and Kerosene

Table 5.13 describes the percentage change in welfare as measured by the volume of total consumption (change in new volume as a % of previous volume as measured by previous price) for the policy changes considered relating to petrol, diesel and kerosene. For each of the four policy reforms, we see that the results are broadly similar. The bottom deciles fare worst in each case. The higher in the income distribution the less the effect. In fact, for elasticity assumption 7 and 8, the top deciles become net gainers due to the fall in the price of petrol. The reason for the fact that the losses are more concentrated at the bottom is that the introduction of a tax on kerosene hits the bottom of the distribution more. In general the percentage falls in welfare are lower for these reforms than the previous ones. This is primarily due to the lower rate of duty on diesel. As we saw above there is quite a high degree of diesel usage (direct and indirect) for all deciles, compared with kerosene and petrol. Hence a shift in duties from diesel to kerosene would result in lower price increases for other goods.

Policy Reform: Petrol, Diesel and Vehicle Taxation

Table 5.14 describes the percentage change in welfare as measured by the volume of total consumption (change in new volume as a % of previous volume as measured by previous price) for the policy changes considered relating to petrol, diesel and vehicle excise duties. As the price changes are very different from policy to policy, the results are quite different. Again, however, the effects are small. The broad shape of the impact of the reforms is similar to those in Table 7. In the case of policy 9, the overall effect is negative, with deciles losing about a fifth of a percent. Policy 10 is virtually impact neutral, with all deciles gaining by a few hundreds of a percentage point. In policy

reform 11, all deciles gain, with higher deciles gaining more than lower deciles. No duty on diesel eliminates to a large extent the indirect effect of the tax through prices of other goods and services. Finally policy 11 has the strongest effect. The welfare loss here is the highest at about 1 percentage points of consumption for most deciles.

Table 5.13: Welfare Change (% Change in Pre-price change consumption) by Consumption Decile for Petrol, Diesel and Kerosene Reforms (Set 2)

Reform	5	6	7	8
Elasticity	0/0/0	0.1/0.1/0.1	02/0.1/0.1	0.8/0.4/0.2
Price Change (Petrol/Diesel/ Kerosene)	-0.401/0.086/ 0.576	-0.401/0.088/ 0.578	-0.402/0.085/ 0.574	-0.409/0.072/ 0.554
Decile				
1	-0.13	-0.22	-0.21	-0.27
2	-0.14	-0.21	-0.20	-0.24
3	-0.14	-0.20	-0.19	-0.21
4	-0.14	-0.19	-0.18	-0.19
5	-0.14	-0.19	-0.18	-0.17
6	-0.14	-0.17	-0.16	-0.14
7	-0.13	-0.15	-0.13	-0.06
8	-0.13	-0.14	-0.12	-0.03
9	-0.11	-0.11	-0.07	0.10
10	-0.08	-0.03	0.05	0.45
Total	-0.12	-0.12	-0.09	0.07

Source: SLIEVE

Note: Elasticity and Price Change are given in the order Petrol/Diesel/Kerosene

Table 5.14: Welfare Change (% Change in Pre-price change consumption) by Consumption Decile for Petrol, Diesel and Vehicle Taxation Reforms

Reform	9	10	11	12
Price Change (Petrol/Diesel)	-0.204/0.192	-0.306/0.038	-0.372/0.000	0.000/0.700
Elasticity	0.1/0.1	0.1/0.1	0.1/0.1	0.1/0.1
Decile				
1	-0.21	0.02	0.08	-0.94
2	-0.22	0.01	0.08	-0.98
3	-0.22	0.01	0.08	-0.97
4	-0.22	0.02	0.09	-0.97
5	-0.22	0.02	0.09	-0.99
6	-0.23	0.02	0.09	-1.02
7	-0.22	0.03	0.10	-1.02
8	-0.22	0.03	0.11	-1.04
9	-0.21	0.05	0.13	-1.02
10	-0.15	0.09	0.17	-0.87
Total	-0.20	0.05	0.12	-0.97

Source: SLIEVE

Note: Elasticity and Price Change are given in the order Petrol/Diesel

Fortunately, over the plausible range of price changes, impacts are linear in the proportional price change, and approximately additive across policies, so that it is a simple matter to estimate the impacts on distribution to other possible policy options.

5.4.7 Summary and Sensitivity Analyses

In summary, we note that the budget share of fuels is quite small. Even when one includes the effect of fuels that are used as inputs to other goods and services such as public transport, the percentage of total consumption on fuels is less than 5% for the top decile and 3.5% for all households. We note that the distribution of fuel expenditure is much more even across deciles once indirect expenditures are included. In general the effects on welfare of the policy reforms are small. Policies that include an increase in the duty on kerosene have a relatively stronger impact on the poor than do policies that focus on petrol and diesel duties alone. However the latter set of policies are more likely to increase the price of other non-fuel goods and services and so have a higher, although less distributionally strong, impact on welfare. Nevertheless the amounts are relatively small.

Finally we consider whether the results are sensitive to the assumptions that were made. Firstly utilising the existing 1994 input-output table adjusted for price but not volume changes will underestimate the amount of fuels used as inputs into other goods and services consumed by households as total fuel consumption increased at more than the rate of economic growth. Therefore the welfare effects would be expected to be stronger. However, as the existing effects are quite small, a proportional change resulting from the under-estimate will still result in a small effect on welfare. A further assumption made relates to the proportions of petrol and diesel consumed by households. Sensitivity tests carried out indicate that results are reasonably robust to this assumption. This is because direct fuel consumption is low and so much of the effect of price changes would feed through the inputs of goods and services purchased. This is a result that is unaffected by assumptions about the distribution of expenditure by households on petrol and diesel. Thus while the quantitative effect may differ depending upon the assumptions, the results would not in general be qualitatively different.

5.4.8 Conclusions

Household expenditure survey and input-output data for Sri Lanka are used to assess the welfare effects of changing fiscal policies. The share of expenditure on fuel is a small percentage of total expenditure, averaging 5% for the top decile and 3.5% for all households. These percentages include the direct consumption of fuels *and* the indirect consumption via purchases of other goods and services. The welfare effects of changing duties are, therefore, modest.

Policies that include an increase in the duty on kerosene have a stronger effect on the lower income deciles than do policies that focus on petrol and diesel duties. Taxes on petrol are progressive, those on diesel relatively neutral.

5.5. VEHICLE EMISSIONS AND POLLUTION COSTS

We noted earlier that the proper taxation of road fuels must balance a number of conflicting objectives – revenue raising, road user charging and charging for the damage done by pollution. The purpose of this last component of the fuel excise duty is to encourage road users to choose less polluting alternatives where these have lower total social costs, as well as possibly to raise revenue to pay for the extra health costs of treating those adversely affected. Fuel taxes are, however, a relatively blunt instrument. They cannot distinguish between different vehicles that emit very different levels of pollution per litre of fuel used. Carbon dioxide, CO_2, emissions are directly proportional to fuel use, and it does not matter where the fuel is consumed, but for other pollutants, the damage depends on where the emissions occur. Thus SO_2 emissions depend only on the sulphur content of the fuel, and not the characteristics of the vehicle, but the damage is higher in populous urban areas and still wind conditions. Emissions of other pollutants, notably particulates, PM, depend very much on the age, type and condition of the vehicle, while the damage again is location and time specific. Other regulatory instruments may be needed to deal with serious pollution problems, and various standards and prohibitions may be necessary. Ideally, though, these should be informed by estimates of the pollution damage caused by the type of vehicle and fuel.

We need to estimate three types of pollution cost for three different purposes. The first and most basic is the average pollution damage per litre of fuel, averaged over all vehicles of that fuel type. At some later stage it may be possible to be more selective in targeting additional annual license fees on vehicles inflicting above average damage per litre consumed, and choosing a more representative vehicle to assess the pollution tax, but for the moment we take this rather simple approach. The second estimate is the particular extra damage done by alternatives to petrol-powered cars, to see how far this influences the extent to which such vehicles should be more heavily taxed through fuel duties and/or license fees. Finally, we need an estimate of the annual damage done by two-stroke rather than four-stroke motor cycles and three-wheelers, to see what extra purchase penalty or annual license charge should be levied on those (or whether they should just be banned).

5.5.1 Rough estimates of fuel pollution costs

Rough estimates of average pollution costs can be derived from Lvovsky *et al*, (2000, Table 6.3, p65), which gives US$ health cost damages per tonne pollutant per US$1,000 per capita income. The per capita income of Sri Lanka is $800/hd. The

population of Colombo is about 2 million,[18] so if we consider the major impact of pollution to be in Colombo, we multiply the numbers in Table 6.3 (which are in U.S. $/ton per million local inhabitants per US$1,000 per capita income) by 1.6 (2. million inhabitants, $800 income). As a further rough check we can multiply the aggregate results for Mumbai by 0.3 (allowing for the different size of population, 12 million, and income per head, $450/head compared to $800/head) or Bangkok (population 5.9 million, income $3225/head) by 0.084, as discussed below.

If we consider the first objective, to measure the average damage done, then we need to estimate the cost per kg of pollutant, and relate that to the kg emissions of pollutant per tonne of fuel. Table 6.3 from Lvovsky *et al* (2000), allows us to calculate the cost per kg of pollutant from low stack sources such as vehicles, including the cost of elemental sulphur, which is the form in which it is contained in fuel:

PM_{10}	$3.114 x 1.6	= $5/kg (range $1.1 – 10.4)
SO_2	$0.487 x 1.6	= $0.8/kg SO_2 (range $0.2 – 1.7)
S		= $1.6/kg S (range $0.4 – 3.3)
NO_x	$0.123 x 1.6	= $0.2/kg (range $0.05 – 0.4)

5.5.2 Alternative estimates based on Sir Lanka pollution levels

A better approach would be to work back from the emissions released in Colombo to the effect on pollution of PM_{10} etc in micrograms/cu.m (μg/ m^3) and then deduce the impact on mortality. Unfortunately we do not have access either to good data on current pollution levels, or on the fraction attributable to vehicles in Colombo, so at best this can provide a very rough cross-check. The only two observations we have on pollution levels are for the period 1998-2001, which gives an average of 81 μg/m^3 (SD=22 μg/m^3), and for 2000, which has a value of 73 μg/m^3 (SD 17 μg/m^3). The figures relate to Fort Station, which is a hot spot, and hence these numbers greatly overstate the ambient levels experienced by the majority of the urban population. If we assume that the average over Colombo is only 50% of this level of 73 μg/m^3, or 36.5 μg/m^3, and that 80% of that is transport related, then the result is 29.2, or roughly 30 μg/m^3.

The next step is to relate changes in pollution to changes in DALYs (Disability adjusted life years). We take as our estimate that an increase of 10 μg/m^3 in pollution raises the daily mortality rate by 1.3% (which is an average value found for Bangkok, (EF&EE, 2002, p5). It follows that the 30 μg/m^3 PM attributable to traffic in Colombo raises daily mortality by 4%. The resulting effect assuming that everyone in Colombo experiences this increase over their whole life (i.e. the increase is *permanent*) would be

[18] The actual population was recorded as 2,234,000 in June, 2001. The lower figure is retained to avoid suggestions of spurious accuracy, given the large error bounds on the computed costs.

0.34 DALYs, using a model roughly calibrated to the current life expectancy and neonatal mortality of Sri Lanka. (An illustration of the effect of a rather greater increase in pollution of 75 $\mu g/m^3$ which causes a 10% increase in mortality in Figure 5.6).

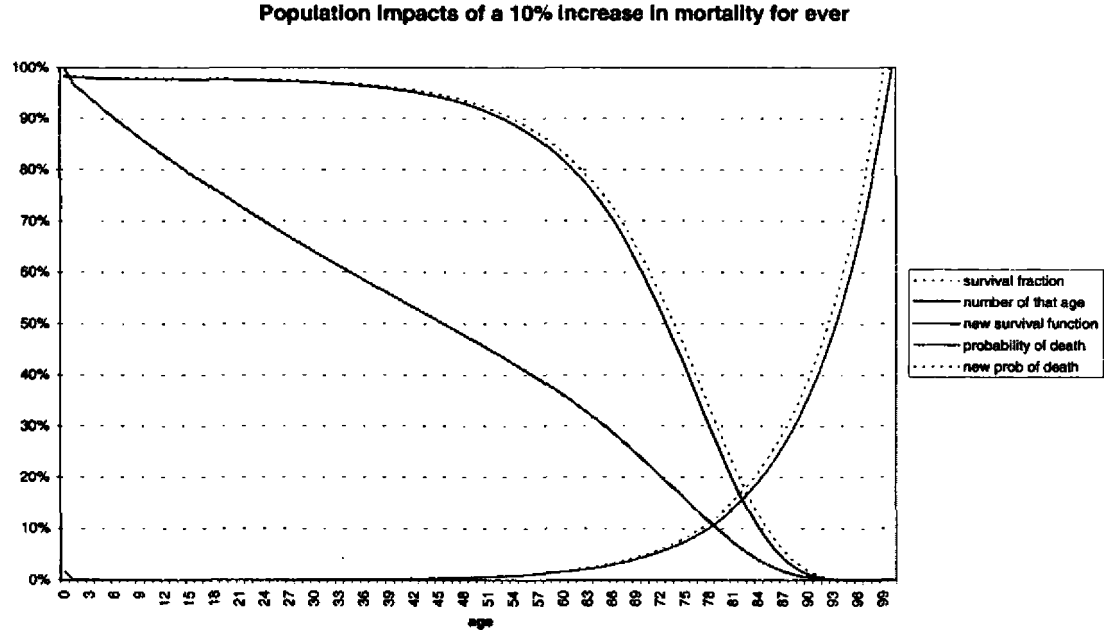


Figure 5.6: Effects of a permanent increase in pollution

If instead we ask more usefully what the effect of an increase over just one year would be (so that we can relate this effect to the emissions of PM) then the effect is 0.0038 DALYs (or just 1.2% of the effect of a permanent change). If all 2 million inhabitants of Colombo are exposed then this amounts to 7,700 DALYs. If we knew the weight of particulates released by vehicles in Colombo then we could estimate the DALY/tonne PM. Unfortunately, the figures provided by Enstrat International Ltd in their report 'Motor Fuel Quality Improvements' are considered very unreliable. The estimates are based on European emission levels and were then averaged over the whole country. The figure provided by Enstrat for 2000 was 7,780 tonnes PM for the whole country. If we assume that 33% of total PM emissions were in Colombo, then we could associate the damage done to 2,567 tonnes of PM. In this particular case the damage could be described as 3 DALY/tonne PM. If we take the UK ratio of DALY/per capita GDP of 3, then the Sri Lankan value of a DALY is US$2,400, and the morbidity health cost of particulates would be US$7,200/tonne or $7.2/kg. This is rather higher than the estimate of $5/kg derived above (though it lies within the range of the Six Cities Study). If we took the ratio of DALY/per capita GDP from Lvovsky *et al* (2000) of 7.43, the estimate would be US$18/kg, which seems too high.[19] If we have

[19] The value of a DALY in the UK is £30,000 to £50,000 and GDP/head is £16,500, so the ratio is 1.8-3. The figure in Lvovsky *et al* (2000, table 4.4) is higher as they work back from the value of a premature mortality avoided, which is taken as 10 DALYs, not 40 DALYs, as would be appropriate for road accident fatalities, on which the UK figure is taken.

underestimated the contribution of traffic to PM or the exposed population, then the number will be lower, but if we have overestimated the tonnage of PM released in Colombo the damage cost will be higher.

Clearly there is considerable uncertainty about the emissions data and the various assumptions on which this estimate rests. It therefore seems preferable to take the Six Cities estimates listed above, noting that our preferred estimate based on pollution data lies within the range of that study. The cost of sulphur damage for diesel with 1% by weight is the damage done by 10kg/tonne, or 1.33 US cents/litre, 1.25 Rs/litre per % of S, and for petrol would be 1.1 Rs/litre per % of S by weight. It is important to distinguish between the legal limits on sulphur content and the actual values, which are lower. Thus for petrol the value is close to zero (and will be taken as that), while for diesel the value is 0.6-0.7%. The actual cost of sulphur damage for diesel will therefore be taken as 0.8 Rs./litre, and for petrol, zero.

It is perhaps worth commenting that the benefit of reducing sulphur in diesel from 1% to 0.5% is a reduction of 5kg/tonne of sulphur worth 0.63 Rs/litre. The benefit of reducing this from 0.5% to 500ppm or 0.05% is 4.5kg/tonne or an extra 0.56 Rs/litre, though the extra cost involved in making this additional reduction may be appreciable. Providing fuel is taxed on sulphur content the tax will adjust automatically to improvements in quality.

5.5.3 Costs of vehicle pollution

Ideally, the next step would be to determine the relative contributions of various vehicles to pollution. Sulphur dioxide emissions will be strictly in proportion to the sulphur in the fuel, and independent of the vehicle. Its cost per litre for petrol and diesel has already been computed above.

As noted above, the data provided by Enstrat International Ltd in their report 'Motor Fuel Quality Improvements', are not considered reliable enough to allow any apportionment of pollution to particular vehicles. If we had more reliable measures of tail-pipe emissions factors by type of vehicle and driving condition, it would be possible to estimate the pollution cost per km driven and per litre of fuel consumed. Enstrat estimate that in 2000 80% of PM emissions came from diesel vehicles, with the main source of petrol PM emissions produced by motor-cycles and tri-cyles.

Using the admittedly unreliable emissions data for different types of vehicle in gm/km for PM and NO_x it is possible to see how variable the implied emissions damage per litre of fuel consumption is across different vehicles. If different vehicles emit very different levels per litre of fuel, then a fuel tax to reflect emission costs would be poorly

targeted. The rather weak evidence suggests that emission costs per litre do not vary excessively across different categories of vehicle. On that basis the pollution tax per litre could defensibly be set at the average for all vehicles. The main objection to this approach is that newer and better maintained vehicles within any category may be over-taxed, while older or poorly maintained vehicles would be under-taxed. That is an argument for lower average pollution taxes combined with vehicle inspections, fines for exceeding limits, and possibly higher annual licence charges for high emission vehicles.

If we take Enstrat' estimates of total PM emissions in Sri Lanka as 7,780 tonnes, of which 80% is attributable to diesel vehicles, and if we take Enstrat's figure for total road transport diesel consumption in 2000 as 1,316,000 tonnes (=1,566 million litres), then emissions from diesel average 4 kg/'000 litres. If we take the damage cost per kg PM as $5/kg, then the damage per litre is 2 cents/litre or 1.9 Rs/litre. Add to this the sulphur damage cost of 0.8 Rs./litre and a NO_x damage cost of 0.5 Rs./litre gives a total urban damage cost of 3.2 Rs./litre. More accurately, this would be 2.4 Rs/litre plus 1.25 Rs/litre/% of sulphur by weight. The pollution tax on petrol would be almost zero, given the low PM and NO_x emissions and the zero sulphur content, though the same sulphur tax would apply.

We can cross-check these numbers using figures for Mumbai and Bangkok in the Six Cities study, using the assumptions set out in Lvovsky *et al*, (Appendix 1). Those suggest that petrol creates roughly 10% of the damage per litre as diesel. In Mumbai, the petrol and diesel consumption there is 20kg/cap x 12 million = 240kt/yr. Allowing for the lower damaging effect of petrol, the total diesel equivalent is 260kt/yr. The health impacts from vehicles are $US 38 million, or $146/tonne diesel. If we then multiply the results for Mumbai by 0.3 we obtain $44/tonne, or 3.4 Rs/litre, close to the estimate of 3.2 Rs/litre above.

If we work back from estimates for Bangkok, consumption of diesel equivalent in vehicles is 673kt/yr, causing health damage of $480 million, or $714/tonne diesel. Again we multiply the results for Bangkok by 0.084 to give $60/tonne, or 4.7 Rs/litre, somewhat higher than the estimate above. Taken together these might suggest that the 3.2 Rs/litre as the estimate of the damage cost for urban diesel seems reasonable.

The next issue to address is how best to reflect this pollution damage in a tax. There are two problems to address. The first is that the damage costs estimated above are for diesel used in the most populous place. We assumed that damage was directly proportional to the exposed population, but outside Colombo the population exposed to each vehicle will be lower and hence the damage also lower. Averaging over the whole country might reduce the damage cost by 50% per litre of fuel. Second, emissions

increase with the age of vehicle. Enstrat (2002, Table A8-10) suggests by as much as 40% after 120,000km, though they also suggest that high emitting vehicles may have emissions 2-3 times average, due to "malfunctions, poor maintenance, old age, etc." The implication is that a pollution tax of 3.2 Rs/litre on diesel would overtax non-urban and more recent or better maintained vehicles, and under-tax older urban vehicles. One compromise would be to set the tax rate at 1.5 Rs/litre and impose higher annual license fees of vehicles that are not able to meet specified emission standards, thus providing the required incentive to maintain and efficiently replace more polluting vehicles.

The figures on particulate emissions from motorcycles are particularly problematic. A recent report "Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles" (Kojima, Brandon and Shah, World Bank, 2000) noted that "data on emission factors for particulate matter must be interpreted with caution. No established methodology is accepted industry-wide for measuring particulate emissions from two-stroke engines. A reliable and reproducible methodology for measuring particulate matter emissions from two-stroke engines should be developed and statistically significant data collected to enhance understanding of emissions from these vehicles and help policy makers select optimal measures for curbing emissions."

Emissions from two-stroke motorcycles are both very uncertain and variable depending on condition, additive quality, etc. If emissions vary from 0.1 to 0.3 gm/km, the damage cost would be 50-150 Rs/'000km. Four-stroke motor-cycles probably have less than one-quarter the emissions per km. That suggests that if motor-cycles are used 5,000 km/yr the *extra* cost (which might possibly be reflected in an annual license fee) might be 190-560 Rs/yr. Clearly there is considerable uncertainty about this number. If motor-cycles last 13 years and if the lower figure is capitalised into the import duty or initial registration charge the amount would be about 1,500 Rs. This is considerably less than the current price difference and so there is no case for banning two-strokes.

5.5.4 Conclusions

At least 80% of the PM emissions from road transport appear to come from diesel vehicles. Heavy trucks and buses are almost certainly the main source of these pollutants, probably accounting for over half of the total. There are sound economic and technical reasons for these large vehicles to use diesel and there is no case for switching these to petrol vehicles. However, older vintages of vehicles have much higher rates of pollution and so reductions in the age of vehicles can have substantial effects on pollution. There is scope for reducing this pollution by administrative action and enforcing a regime of vehicle testing. Fiscal policy can be more effective in dealing with the other main source of these pollutants. Perhaps almost one-fifth of the diesel PM emissions are from pick-ups and dual-purpose vehicles. Taken together vehicle import duties, fuel taxes and vehicle age related rules for imports have favoured

imports of diesel dual-purpose vehicles. If these biases were reversed, pollution would, in time, be reduced.

Enstrat estimate that 20% of PM emissions come from petrol engines, though this could be an overestimate. Here the major contributor is motor cycles and three-wheelers with two-stroke engines. Fiscal changes would be a blunt instrument for dealing with this source of pollution, and the only instruments readily available would be a differential annual levy on two-stroke (compared to four-stroke) vehicles or a differential registration fee. However, the benefits of policies to reduce pollution from motor cycles are likely to be limited in the short run because the main source of pollution is the existing stock of older bikes.

The costs of PM pollution in Colombo, the most serious source of vehicle pollution, are estimated to be about $5/kg. In addition to PM pollution, lead and sulphur concentrations in Colombo are higher than recommended by the World Health Organisation. Total damage cost per litre of transport diesel fuel in Colombo is estimated at 3.2 Rs/litre, though there is considerable uncertainty in this figure, with a range of possible values from less 1 Rs/litre to perhaps 10 Rs/litre. Our preferred estimate for the country-wide average is 1.5 Rs/litre.

5.6 POLICY OPTIONS AND CONCLUSIONS

The initial problem we were required to address was the rapid growth in diesel consumption compared to petrol consumption for road transport, and the consequential impact on air pollution in Colombo. Vehicle particulate emissions grew 68% between 1991 and 1996, or by 9% per year.[20] From 1990 to 2002 the average annual rate of growth of auto diesel consumption was 10% whilst that of petrol was only 3%. The elasticity of fuel consumption with respect to GDP is 1.9 for auto diesel and only 0.6 for petrol. The simple explanation is the relatively high tax on petrol and very low tax on diesel encourages private car users to substitute diesel-powered cars for petrol alternatives, which they would not have done if the taxes on both fuels were similar.

Closer investigation suggested that this interpretation is indeed too simple. The proportion of cars that are diesel powered is modest, and does not appear to be increasing. The elasticity of car ownership with respect to GDP is slightly above 1, which seems rather low given the relatively low level of car ownership. What appears to be happening is that the difference in the age limit between imported cars and vans makes petrol cars more expensive than diesel vans. Consumers who might otherwise have bought cars instead buy lower priced vans or dual purpose vehicles, and most of these run on diesel. Whereas car ownership has been growing at 5-6% p.a., and heavy trucks at about 6%, in line with real GDP growth, that of vans and dual purpose vehicles has been growing at 8-9%, and of all vans plus cars at 7%. The GDP elasticity of all vans is 1.5-1.8, and that of vans plus cars is about 1.3. This evidence is consistent with an increasing shift from cars to vans. Consumers who are not rich enough to buy vans presumably buy motorcycles. Most motorcycles are very polluting two-stroke models. Although they run on petrol they require mineral oil for lubrication. The quality of this appears low, and is a considerable part of the explanation for high levels of pollution from this source.

Policy makers have a variety of options available to address these problems, but the choice of policies requires care if they are to be effective, efficient, and politically acceptable. A policy that successfully banned the import of two-stroke vehicles would not have much immediate effect on pollution from existing two-stroke vehicles, but it should gradually reduce this source of pollution compared to a 'do-nothing' policy as four-stroke vehicles increasingly displace two-stroke models that reach the end of their life. Such a ban would, we find, probably be economically inefficient and it would almost certainly be politically unattractive. In this chapter we first list various policy options, then compare them against the criteria of effectiveness, efficiency, and

[20] Chandrasiri and Jayasinghe, (1998), 'Health effects of vehicular emissions in Colombo', University of Colombo: Department of Economics

political acceptability, in order to guide the choice of the best combination of policies to address the present problems.

The first policy is to consider raising the tax on diesel fuel relative to that on petrol. We consider the arguments in favour of higher diesel taxes, including a proper charge for road use and road damage, and a charge for environmental damage. We also consider the arguments for higher taxes on petrol than on diesel, and the fiscal consequences now and in the future for these fuel tax choices. Fuel taxes by themselves are relatively blunt instruments for guiding the choice of vehicles, for which initial registration fees (and subsequent change-of-use fees) and annual licence fees are better suited. These, in combination with the import tax regime and age rules for vehicle imports, already have a potent effect on vehicle choice. Import bans on certain types of vehicle have certain attractions but many drawbacks. Finally, improving fuel quality and providing incentives for better maintenance and removal of irremediably polluting vehicles may also be useful adjuncts to our fiscal policies, but are being considered by other consultants. Nevertheless, even these policies should be subject to a benefit-cost test, and here some of the quantified evidence we have assembled may be useful.

We start with evidence on costs that might justify an increase in current diesel taxes. It is a good principle of taxation to confine taxes to final consumption, provided that it does not introduce significant distortions. As a general rule, commercial vehicles (that are heavier and drive higher annual distances) should on efficiency grounds run on diesel, while it is normally more efficient for lighter vehicles to run on petrol. There is therefore a reasonable match between desirable fuel choice (diesel vs petrol) and whether or not the use is for production (commercial activities) or final consumption. If other taxes and fees can ensure that individuals are dissuaded from incorrectly choosing diesel vehicles for personal consumption, then diesel taxes can be set primarily to achieve efficiency rather than to raise revenue for redistributive purposes (i.e. from wealthier vehicle owners to socially more deserving purposes). Petrol taxes can then address these other tax concerns.

On efficiency grounds diesel taxes should cover the appropriate road user costs and environmental damage of commercial vehicles. In chapter 5 we estimated the cost of emissions for diesel as 3.2 Rs/litre in urban areas and 1.5 Rs/litre averaged over the whole country, at current levels of sulphur. If Super Diesel has 5000ppm less sulphur than normal diesel then the emissions cost would fall by 0.6 Rs/litre in urban areas, and perhaps 0.3 Rs/litre averaged over the whole country. By itself this differential is unlikely to encourage the use of Super Diesel unless this were required by the pollution control equipment installed on the vehicle. The first cost element to be reflected in the diesel tax is therefore a 1.5 Rs/litre pollution charge.

We do not have reliable estimates of the costs of providing the road network but they are likely to be appreciable per litre of fuel consumed. In 1992 the share of road expenditure in GDP appeared to be about 1% (World Bank Report 16269-CE, 1997, p19, p25). Most of this appeared to be investment, and maintenance was considered to be below the efficient level. Investment levels in the past have been higher, and the interest on the modern equivalent asset value of the road network might be 1% of GDP or higher. If maintenance should be 0.2 of 1% of GDP, then these road costs might be 1.2% of GDP in 1992. At 2000 prices this would amount to Rs 8.8 billion. Consumption of all transport fuel in 1992 was 929 million litres, so a very rough estimate of road costs per litre would be 9.5 Rs/litre (but higher for the more damaging diesel vehicles). If we use the estimated road expenditure of 2001 of Rs. 14.3 billion, the expenditure per litre amounts to 7.4 Rs/litre. This is not directly comparable to the earlier number, as it compares investment and operating costs against a very rough estimate of the interest on the capital and operating costs. A figure of at least 8 Rs/litre for the level of diesel fuel might be justified on the basis of the correct share of GDP, but, as mentioned below, it would be desirable to conduct a more systematic road user cost study to improve this estimate.

If, as in many advanced countries, these road user charges were recovered by a combination of fuel excise duties and annual license fees, then diesel tax rates would have to increase appreciably. Table 5.1 of Section 5.2 showed that diesel was bearing a pure fuel tax of 5.7 Rs/litre (Line **H**). The road user charge of 8 Rs/litre and pollution charge of 1.5 Rs/litre would justify a road user charge of 9.5 Rs/litre, suggesting that the diesel price should be raised by some 3.8 Rs/litre to 29.8 Rs/litre, or by 15%. The combination of these charges thus moves diesel prices closer to current petrol prices, and can be justified on pure efficiency grounds, ignoring the beneficial effects of reducing the distortion created by the higher petrol prices. The new price is close to the equal revenue yield tax rebalancing reported in Table 5.5 of Section 5.3.

Pollution costs for petrol vehicles (except two-stroke vehicles) appear negligible and the road user charge element is also lower than for diesel as cars do less road damage and take up less space than larger diesel vehicles. The logic of additional petrol taxes over and above these elements is that they serve as a useful form of indirect tax on relatively better off consumers, and are a very cost-effective way of raising Government revenue. It is possible to retain a higher petrol than diesel price providing that the choice of vehicles is guided by compensatory charges where appropriate. In some cases it may be simpler to prohibit diesel-powered vehicles below a certain weight, but in other cases it may be necessary to impose an additional annual license fee that reflects the lost value of annual differential tax revenue. First, though, we discuss the consequences of moving to an equal tax per litre on each fuel.

If no other changes were made, the effects of equalising taxes of petrol and diesel should have beneficial effects on pollution in the longer run. At present taxes, most cars are already petrol powered, and that tendency would be reinforced. Current fuel prices encourage buyers to purchase diesel rather than petrol vans, though this is offset by the considerably higher import duty on the more expensive diesel versions. Equalising the fuel taxes without changing the import tax regime would certainly make it more attractive to buy petrol versions, and arguably would over-encourage the purchase of petrol vehicles. The main distortion at present is that potential car owners are encouraged by the high *ad valorem* import duties to buy older and cheaper dual-purpose vehicles (vans) that are, under the current tax regime, normally diesel powered. The incentive to buy vans would remain strong, though now there would be little reason to buy the diesel version. Over time, then, the proportion of diesel powered vans would decrease. The advantages of equalising fuel taxes and thus encouraging consumers to switch to petrol-powered alternatives are therefore worth having. Diesel cars and vans contribute less than 20% of total vehicle particulate emissions, while trucks contribute almost half, so it is important to keep the potential benefits in perspective. In terms of efficiency and (longer term) effectiveness in addressing pollution the policy is desirable. Raising diesel taxes is likely to be unpopular, and would have adverse effects on the price of urban bus commuting. Lowering petrol taxes would be politically appealing, and might provide the excuse to raise diesel taxes.

Although it is difficult to measure the pollution caused by motor cycles with any precision, Enstrat estimated that possibly as much as 20% of the total transport PM emissions might be attributed to two-stroke motorcycles and tricycles. Again, this needs to be kept in perspective, as the social cost per kilometre from these vehicles is still lower than from diesel cars and light vehicles and certainly lower than from buses and trucks, which contribute to the larger part of total pollution.

Probably the most direct way of reducing pollution from motorcycles is to improve the lubricant quality and ensure that properly formulated two-stroke lubricant is cheaper than other alternatives for motorcycle users. This policy would have the advantage of affecting the entire population of vehicles and hence having a larger effect than persuading buyers to choose the less polluting four stroke alternative. Our best estimates of the cost of pollution per km from two-stroke vehicles is 50-150 Rs/'000km. At 5,000 km per year the extra costs are modest compared to the current extra cost of four-stroke vehicles. One logical policy is to impose an additional registration charge on two-stroke vehicles of perhaps 1,500 Rs. At present price differentials that is not enough to encourage much switching. If the price of four-stroke vehicles has been maintained at above competitive levels, and if this monopoly mark-up can be reduced, then the combination of the registration tax and lower four-stroke vehicle prices may encourage a gradual switch.

The same effect could be achieved with more certainty by a ban on imports of two-stroke vehicles. However, this would certainly be unpopular, and will start to have an appreciable impact only after several years, when a significant portion of existing vehicles have beenscrapped. In any case, it has been shown in chapter 5 that there is no economic case for banning the import of two-stroke vehicles.

The next section gives rough estimates of the potential environmental benefits of switching all light vans and dual-purpose vehicles imported from now on to petrol only choices. Whether this is achieved by an import ban, a sufficiently high differential import duty combined with equal fuel taxes, or an annual registration fee, is not particularly important for the purpose of estimating the pollution impact. Our projections are based on a continuation of the GDP growth rate and our estimates of elasticities of vehicle demand, modified by the impact of our most optimistic tax scenario – that of raising the price of diesel to the current level of petrol and assuming or ensuring that no kerosene adulteration takes place.

5.6.1 Effects on emissions of phasing out light diesel vehicles

We assume that diesel prices rise from the current level of 26Rs/litre to 29 - 30 Rs/litre in line with the revenue-neutral option considered in Section 5.3. We assume in addition that either import duties or registration fees are adjusted to make diesel dual-purpose vehicles more costly to operate than petrol alternatives, or (less attractively) that diesel dual-purpose vehicles are banned. For whatever reason, we therefore assume that no new registrations of diesel light vehicles (cars and vans) take place from now on. As a result the fleet of diesel cars and dual-purpose vehicles will gradually decrease as old vehicles are discarded at the average death rate of these diesel vehicles between the years 1998 and 2002.

Table 5.15 below shows the PM emissions that we project from the present to 2020, assuming current emissions rates and business as usual, for diesel cars and light vehicles and trucks (which together accounted for around 60% of total emissions from diesel vehicles in 2000, the rest coming from buses, land vehicles and two-stroke vehicles). In the business as usual scenario the number of diesel cars and dual-purpose vehicles are assumed to increase at the current rate and the fuel choice per vehicle is assumed to remain the same. The left-hand side of the table gives emissions of PM in thousand tonnes (kt) per year from each class of vehicle. Under these assumptions PM emissions would increase by over five and a half times by 2020. Note that we have not assumed that fuel quality or even vehicle performance improves for non-fiscal reasons (i.e. because of refinery upgrading and improvements in imported vehicles), as we wish to isolate the effects of fiscal and vehicle licensing policy. As a result we are overstating the benefits to be derived from policy changes.

The right hand part of the table shows the effect of the policy under consideration. We give two estimates of the reduction in PM emissions, one assuming that fuel consumption and emissions remain unchanged per vehicle, the second assuming that fuel consumption responds to the fuel price change with a fuel-price elasticity of –0.1 (low because it primarily affects trucks, rather than light vehicles). If the policy of phasing out diesel cars and dual-purpose vehicles were implemented, and these vehicles were gradually replaced by petrol equivalents, PM emissions from these vehicles would increase to only twice the current level. The sixth column on the table shows the absolute difference that could be achieved in kt per year, assuming no reduction in fuel consumption per vehicle. The reduction is slightly greater assuming a response to the diesel price consistent with a revenue-neutral fuel duty change to make both petrol and diesel duties equal in absolute terms (as detailed in Table 5.5 in Section 5.3). The resulting difference in absolute kt of PM emitted per year is shown column 7 of the table, and the percentage reduction relative to business-as-usual given in the last column.

Table 5.15: Impact of policy on PM emissions from light vehicles and trucks

	PM emissions from diesel - business as usual kt per year				Reductions due to policy kt per year	kt per year	Percent
	Cars and LGV	Pickups and dual purpose	Trucks	TOTAL	no fuel price response	fuel responds to price	reduction With price response
2000	0.15	1.25	3.32	4.71	0.00	0.21	5%
2001	0.15	1.27	3.44	4.86	0.00	0.22	5%
2002	0.15	1.30	3.56	5.00	0.00	0.23	5%
2003	0.15	1.49	3.77	5.42	0.32	0.55	10%
2004	0.16	1.71	3.99	5.87	0.66	0.90	15%
2005	0.17	1.97	4.23	6.37	1.02	1.27	20%
2006	0.18	2.26	4.48	6.92	1.41	1.67	24%
2007	0.19	2.60	4.74	7.53	1.84	2.10	28%
2008	0.21	2.98	5.02	8.21	2.31	2.58	31%
2009	0.22	3.42	5.32	8.96	2.84	3.11	35%
2010	0.23	3.93	5.64	9.80	3.42	3.71	38%
2011	0.25	4.52	5.97	10.73	4.07	4.38	41%
2012	0.26	5.19	6.32	11.77	4.81	5.13	44%
2013	0.28	5.96	6.70	12.93	5.64	5.98	46%
2014	0.29	6.84	7.09	14.23	6.59	6.94	49%
2015	0.31	7.86	7.51	15.68	7.66	8.03	51%
2016	0.33	9.03	7.95	17.31	8.89	9.27	54%
2017	0.35	10.37	8.42	19.14	10.28	10.69	56%
2018	0.37	11.91	8.92	21.20	11.88	12.30	58%
2019	0.39	13.68	9.45	23.52	13.70	14.15	60%
2020	0.42	15.71	10.01	26.14	15.78	16.25	62%

Source: own calculations using data from Table 5.7 of section 5.5.

5.6.2 Future Revenue Impacts

Looking ahead, the revenue forecasts are favourable provided the real tax per litre of fuel is at least maintained, as the GDP elasticity of total road fuel is 1.65. Provided real taxes per litre are maintained, the contribution of fuel excises to the budget will gradually increase. In the past, fuel excises have been held moderately constant in money terms and have therefore eroded in real terms. Unless fuel excises are indexed to the consumer price level, they will not maintain their real value. If real taxes fall at more than 3% p.a., fuel duty revenue will decline as a share of GDP. Thus if inflation is 8% p.a. the fuel excises will have to rise by at least 5% p.a. to keep their revenue share – and this has not been true of petrol taxation in the past. Once the government has decided on the differential tax (if any) between petrol and diesel it will have to make sure that revenues as a share of GDP are kept at least constant.

5.6.3 Reforming import duties and license fees

Reforming the import tariff structure is a more challenging task. There is some logic in an *ad valorem* tax, as that is roughly proportional to the remaining life of the vehicle (for a vehicle of given initial cost) and thus very roughly approximates to a charge per year proportional to that value. However, international prices are determined by the depreciation rates in the exporting country, not those in Sri Lanka. In Japan for various vehicle-testing reasons, vehicles have a relatively shorter life and therefore depreciate more rapidly than they would in a low income country where maintenance and repair charges are relatively lower. The effect is that an *ad valorem* tax encourages importers to buy older vehicles than otherwise, and these embody less stringent emission standards. It might be better instead to have a larger vehicle-specific fixed real component and a lower cumulative *ad valorem* rate to reduce the excessive incentive to import older and cheaper (and therefore more polluting) vehicles. The present import taxes and registration fees do, however, encourage cheaper petrol rather than more expensive diesel versions, and to that extent partly offset the adverse effects of higher petrol than diesel taxes.

One possible solution to the over-encouragement of older more polluting vehicles is to move away from high import duties and instead attempt to collect the same revenue through annual license fees. If the capability of doing this is limited, because these are decentralised to the provincial level, and if there is a lack of confidence about compliance, then the other alternative is to levy a scale of registration charges specific to the engine, vehicle, and possibly age (though this will need careful design). Such a system could discriminate between vehicles meeting different emission standards and could certainly provide incentives to choose the right fuel for each vehicle. (The present differential registration fee already does this.) Another attraction of an initial

registration charge rather than an increase in the annual license fee is that it avoids the transition problem in moving from a high import duty and low annual license fees to the reverse. If this happened, current vehicle owners would pay twice. The advantage of higher license fees is that it encourages earlier scrapping of the most polluting vehicles. The political acceptability of high annual and therefore recurring licence fees is likely to be low, so this option may be ruled out on political grounds.

A much simpler policy option that would reduce the incentive to import older dual-purpose vehicles instead of less polluting cars would be to equalise the maximum age for importing vehicles at that currently for vans. This, combined with the fuel tax changes, should be effective in discouraging dual-purpose imports, reasonably efficient (though still over-encouraging older more polluting vehicles), but surely acceptable if ages are extended.

5.6.4 Conclusions

Our results are sensitive to the accuracy of the data and assumptions we have used. In particular, the choice of vehicles (the break-even analyses) depend on the import prices of comparable alternative choices, maintenance costs, the remaining life, and whether, as we assume, the remaining life depends solely on distance driven.

When determining the appropriate level of duty to levy on diesel, the component representing road user costs needs to be more accurately measured than the rough estimates provided in this chapter. We therefore recommend that a road user charging study be undertaken to assess the charge that can be justified for diesel fuel in order to properly charge for road user costs. We have also had to make rather rough estimates of pollution costs and recommend that these estimates be refined in the light of better air pollution and emissions data that should become available as the quality of monitoring improves. This too will provide information for the correct level of charges on diesel. These two components provide a lower bound on the taxes on diesel, while taxes on petrol should then be set on revenue raising and redistributional grounds, providing that adequate safeguards have been taken to prevent distorting the choice of vehicles.

Over time, policies to transfer demand for diesel dual-purpose vehicles and cars to petrol vehicles would result in a significant reduction in pollution. The analysis showed that the current fuel tax/price policies do not have a significant effect on the choice of fuel type for cars. Vehicle import policies such as age limits for different types of vehicles and high *ad valorem* taxes duties play by far a larger role in encouraging the choice of diesel vans instead of petrol cars. Import tariffs need to take better account of consumer choice and the resulting fiscal and environmental impacts. Banning the import of certain vehicles is a cruder way of achieving similar environmental impacts.

However, we do not advise this policy as we consider that the environmental gains are likely to be worth less than the economic costs. For illustrative purposes, we have projected the effect that eliminating imports of all diesel-fuelled cars and dual-purpose vehicles/light vans would have on particulate (PM) emissions. Compared to a projection of business as usual for the total emissions from trucks, light vans and diesel cars (that in 2000 accounted for over 60% of total PM emissions), eliminating imports would substantially reduce the amount of emissions from these sources. This is the maximum that may be achieved, based on the (unreasonable) assumption that there is no change in emissions per diesel vehicle over the next 20 years, and that *all* imports of diesel vans would be prohibited or otherwise discouraged. Some types of high mileage *commercial* vans (unsuitable as substitutes for private cars) are likely to remain the efficient choice. This case was not analysed as the data provided to us suggests that most vans in Sri Lanka are dual-purpose.

A potential source of instability for government revenue is the effect of inflation that reduces the real revenue from fixed excise duties. The remedies are to index-link any specific excise duties and otherwise set *ad valorem* rates based on import prices, possibly adjusting where the real cost of fuel imports changes.

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APPENDICES

Appendix A: Term of Reference for Air Resource Management Centre

Appendix B: Terms of Reference for Local and International Consultants

Appendix B – 1: Terms of Reference for Vehicle Emissions Reduction (International Consultant)

Appendix B – 2: Terms of Reference for Motor Fuel Quality Improvement (International Consultant)

Appendix B – 3: Terms of Reference for Fiscal Policies on Fuels & Vehicles (International Consultant)

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Appendix C: Presentation Materials of Training Programs

Appendix C – 1: Technician Training Program on Diesel Vehicle Emission

Appendix C – 2: Technician Training Program on Two-Stroke Motorcycles and Three-Wheelers Emission

Appendix C – 3: Training Program on Vehicle Inspection and Maintenance Program for Examiners And Traffic Police Officers

Appendix C – 4: Training Program on Vehicle Emission Testing Equipments for Equipment Monitoring and Verification Officers

Appendix D: Standard Operating Procedures of Emission Testing Equipments

Appendix D – 1: Standard Operating Procedure of the Gas Analyser and Record Keeping Procedure of the Test Results

Appendix D – 2: Standard Operating Procedure of the Smoke Meter and Record Keeping Procedure of the Test Results

Appendix A

Term of Reference for Air Resource Management Centre

APPENDIX A

Term of Reference for

AIR RESOURCE MANAGEMANT CENTER

(AirMAC)

- AirMAC will function as the project office for Urban Air Quality Management Project during the project period, and will carry out all the activities involved in the project.

- The Project Management Unit will have a Project Director, Deputy Project Director and a Project Accountant whose salaries will be paid by the Government of Sri Lanka (GOSL).

- AirMAC will be developed to coordinate all future air quality improvement activities, even after the project is over.

- It will have four Project Assistants whose capacity will be build up to take over the entire AQM programs in the country along with relevant officers in the all take holder agencies. This will be carried out as an Institutional Strengthening Component and will be funded by the IDA Grant.

- Integrate air pollution abatement programs all over the island done by various groups CEA, CMC, MFE, NERD, NBRO, ITI, MD, NSF, CPC, MFP, MOT, DMT, AEA, CCI, and SLAA.

- Disseminate information through the media on current ambient air quality.

- Build an inventory of air pollution sources in grater Colombo & develop an appropriate air quality model.

- Organizing an intensive training workshop for local staff on air quality monitoring & modeling with foreign experts.

- Provide input to GOSL for air pollution control policies & plans, improved enforcement & optimizing air quality management strategies.

- Organize workshops/ awareness programs on Air Quality management

- Establishment of Information Center by collecting of all documents prepared on Air Quality in Sri Lanka and collecting documents related to air quality in other countries.

Appendix B

Terms of Reference for Local and International Consultants

APPENDIX B - 1

Terms of Reference for Vehicle Emissions Reduction (International Consultant)

Background Information:

The government of Sri Lanka has obtained an IDF Grant from the World Bank to strengthen the institutional and policy framework for urban air quality management in Colombo. The overall objective of the proposed activity is to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions.

Institutional Arrangement

A project management unit established at the ministry of Forestry & Environment will implement the Project, and consultants should submit their reports to Dr. B.M.S. Batagoda, Project Director. The consultant will be provided space within the office. They can use facilities available at the project office such as computer, printer, photocopy machine and OHP. The consultants are expected to work with two local counterpart officers and a local consultant during the consultancy period.

The program will consist of three components.

(i) *Vehicle emissions reduction.* The grant will be used to strengthen the capacity of the Department of Motor Traffic, the Planning Unit of the Ministry of Transport, and the Central Environmental Authority for vehicle emissions control, and to assist in revising in-use vehicle emission standards, establishing an inspection and maintenance program, limiting the number of polluting vehicles on the road, awareness-raising, and exploring innovative partnership arrangements and financing mechanisms.

(ii) *Gasoline and diesel quality improvement.* This component will facilitate policy decisions on implementing realistic, fiscally sound and socially beneficial plans for phasing out leaded gasoline, improving diesel quality and rationalising demand for these fuels which is currently distorted by a large price differential. In particular, the grant will be used to examine the feasibility of tightening gasoline and diesel quality standards; analyse fiscal, financial and public health implications of changes in fuel specifications and relative prices as well as the impact of these changes on low-income groups; and recommend possible options to the Government of Sri Lanka.

(iii) *Fiscal Policies on Fuels and Vehicles.* Alternative options for pricing diesel and gasoline and levying duties on different vehicles will be examined, from the point of view of long-term fiscal sustainability, impacts on households' welfare (expenditure) and decreasing most harmful vehicular emissions. While

the activity addresses issues raised during discussions on components (a) and (b), it is proposed as a separate component because of different expertise and main counterpart agency required for its implementation

Components (b) and (c) have overlapping fiscal issues (fuel pricing and vehicle duties), which are covered under, separate terms of reference.

Scope of Vehicle Emissions Reduction and objectives

The government will identify two counterpart staff members who will work full-time with the consultant selected in the IDF grant program for approximately five months to ensure the transfer of expertise and knowledge. The principal activities will be undertaken by the consultant with the two counterpart government staff members identified by the Government of Sri Lanka. Throughout the duration of the assignment, the consultant will work closely with the Department of Motor Traffic, the Planning Unit of the Ministry of Transport, and the Central Environmental Authority.

The consultant will

[1] Review the work of the local consultant to be procured under separate terms of reference who will be collecting and analysing data in Sri Lanka on current and projected future vehicle fleet size, characteristics (age distribution, fuel use, origin), type of valve seat (soft or hard, for the purpose of determining the need for lubricant additives after gasoline lead elimination), and octane requirements (as specified by vehicle manufacturers). Oversee the completion of this assignment and include in the analysis development of vehicle mortality curves;

[2] Formulate and assist in implementing a pilot program for measuring smoke emissions from in-use trucks and the emissions of carbon monoxide (CO), hydrocarbons (HC) and smoke from in-use two- and three-wheelers. In particular,
(a) identify the most suitable emissions measurement equipment for each;
(b) train the personnel designated by the Government of Sri Lanka in the operation and maintenance of the monitoring equipment;
(c) train the trainers for inspection;
(d) write a manual for procedures and proper maintenance and calibration of the monitoring equipment;
(e) develop a record keeping procedure for the test results that would be amenable to analysis (for example, emissions as a function of vehicle age, kilometres travelled per year as well as in total, emissions control technology, usage [private or commercial], vehicle weight, fuel used) while at the same time minimise the chances of tampering by personnel at vehicle villages which are in the process of being set up by the Government of Sri Lanka;
(f) evaluate the current vehicle registration system for the purpose of establishing an effective inspection and maintenance (I/M) program, and make recommendations for, and estimate costs of making, changes needed, if any;
(g) develop procedures for other tests to be conducted at the vehicle villages (for example, visual inspection for safety checks) for the completion of method development;

[3] Together with the Ministry of Transport, establish criteria for selecting vehicles to be tested for inspection as well as the incentive structure for drivers to participate in this pilot program;

[4] Evaluate the current vehicle import policy from the point of view of emissions reduction;

[5] Design a pilot training programme for mechanics, possibly with the assistance of vehicle manufacturers (for example, Bajaj Auto for three-wheelers) or other appropriate bodies;

[6] Analyse the emissions data collected and propose future vehicle emission standards, in-use as well as new, including a schedule for phasing in increasingly tighter standards;

[7] Propose a vehicle inspection system in the Western Province: assist the Government of Sri Lanka in finalising the plan for setting up vehicle villages; identify and cost monitoring equipment required, and level of staffing and training needed. Estimate the overall cost (initial capital as well as annual running costs);

[8] Evaluate the preparedness of vehicle repair shops in terms of equipment and staffing for adequate vehicle maintenance and repair for compliance with the proposed emission standards;

[9] Propose how to deal with non-compliance;

[10] Assess measures for reducing emissions from two-stroke engine vehicles, including supply of 2T oil;

[11] Incorporate lessons from other developing countries.

Schedule and work plan

The consultant will start work in September 2001. The consultant is expected to make a minimum of four trips to Colombo.

Action item	*Start*	*End*
01. Identification trip to Sri Lanka	09/2001	09/2001
02. Select most suitable emissions measurement equipment for this assignment. The equipment may be purchased in 2 phases, in which case finalise the selection of the equipment in the first phase.	09/2001	09/2001
03. Review the current proposal for vehicle villages and standards for in-use vehicles effective 2002	09/2001	09/2001
04. Review adequacy of current vehicle registration system for effective I/M	09/2001	09/2001
05. Evaluate the current vehicle import policy from the point of view of the impact on vehicular emissions.	09/2001	09/2001
06. Participate in the analysis of the vehicle fleet data, and prepare and submit draft report on (a) data analysis; (b) assessment of vehicle village proposal;	09/2001	10/31/2001

(c) assessment of in-use vehicle emission standards; (d) assessment of vehicle import policy		
07. Train personnel on equipment, and write manual for operation and maintenance of monitoring equipment	11/2001	12/2001
08. Submit final report on vehicle fleet data acceptable to the Government of Sri Lanka incorporating comments, including whether or not lubricant additives would be needed after gasoline lead elimination in Sri Lanka for use by vehicles that have soft valve seats	11/31/2001	11/31/2001
09. Develop a record keeping procedure for emissions test results	11/2001	11/2001
10. Devise test procedures other than emissions measurements for vehicle villages	11/2001	11/2001
11. Analyse initial data collected for the purpose of revising in-use vehicle emission standards for trucks and three-wheelers	11/2001	11/2001
12. Prepare for training 500 mechanics	11/2001	11/2001
13. Evaluate and discuss with the Government of Sri Lanka different options for dealing with non-compliance	11/2001	12/2001
14. Evaluate the procedures and emissions test results, and recommend modifications for inspection procedures as needed	01/2002	01/2002
15. Evaluate the training of mechanics, and suggest modifications as needed	01/2002	01/2002
16. Assess adequacy of repair shops for enforcing standards	01/2002	01/2002
17. Propose measures for reducing emissions from two-stroke engines	01/2002	01/2002
18. Prepare a draft interim report summarising all the data, data analysis, observations and recommendations	02/2002	02/2002
19. Submit draft interim report	2/31/2002	2/31/2002
20. Analyse additional data obtained	03/2001	05/2002
21. Finalise recommendations for vehicle villages, outlining a detailed program including procedures as well as equipment/staff requirements and cost estimates, and prepare draft final report for the entire assignment	06/2002	06/2002
22. Submit draft final report	6/15/2002	6/15/2002
23. Submit final report acceptable to the Government of Sri Lanka, incorporating comments received	7/15/2002	7/15/2002

APPENDIX B - 2

Terms of Reference for Motor Fuel Quality Improvement (International Consultant)

Background Information:

The government of Sri Lanka has obtained an IDF Grant from the World Bank to strengthen the institutional and policy framework for urban air quality management in Colombo. The overall objective of the proposed activity is to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions.

Institutional Arrangement

A project management unit established at the ministry of Forestry & Environment will implement the Project, and consultants should submit their reports to Dr. B.M.S. Batagoda, Project Director. The consultant will be provided space within the office. They can use facilities available at the project office such as computer, printer, photocopy machine and OHP.

The consultants are expected to work with two local counterpart officers during the consultancy period.

The program will consist of three components.

a *Vehicle emissions reduction* The grant will be used to strengthen the capacity of the Department of Motor Traffic, the Planning Unit of the Ministry of Transport, and the Central Environmental Authority for vehicle emissions control, and to assist in revising in-use vehicle emission standards, establishing an inspection and maintenance program, limiting the number of polluting vehicles on the road, awareness-raising, and exploring innovative partnership arrangements and financing mechanisms.

b *Gasoline and diesel quality improvement.* This component will facilitate policy decisions on implementing realistic, fiscally sound and socially beneficial plans for phasing out leaded gasoline, improving diesel quality and rationalising demand for these fuels which is currently distorted by a large price differential. In particular, the grant will be used to examine the feasibility of tightening gasoline and diesel quality standards; analyse fiscal, financial and public health implications of changes in fuel specifications and relative prices as well as the impact of these changes on low-income groups; and recommend possible options to the Government of Sri Lanka.

c *Fiscal Policies on Fuels and Vehicles.* Alternative options for pricing diesel and gasoline and levying duties on different vehicles will be examined, from the point of view of long-term fiscal sustainability, impacts on households' welfare (expenditure)

and decreasing most harmful vehicular emissions. While the activity addresses issues raised during discussions on components (a) and (b), it is proposed as a separate component because of different expertise and main counterpart agency required for its implementation

Components (b) and (c) have overlapping fiscal issues (fuel pricing and vehicle duties), which are covered under, separate terms of reference. The elements of the third component specifically addressing technical aspects of fuel quality improvement are described below. The principal counterpart for the study is Ceylon Petroleum Corporation (CPC).

Scope of Motor Fuel Quality Improvement and objectives

The consultant will

[1] Summarise the international as well as regional trends in fuel quality specifications and the factors driving the specification changes proposed. Summarise how refineries are planning to meet the tighter fuel specifications, particularly in Asia. Concentrate especially on refineries and countries with similar refinery configurations and petroleum product import/export patterns to Sri Lanka, described in [3] below.

[2] Based on [1], select fuel quality parameters that would need to be tightened (for example, sulphur in diesel, diesel distillation control, and gasoline RVP) or new limits to be introduced (for example, benzene and total aromatics in gasoline, and manganese as in MMT) covering the period between now and the year 2015 in Sri Lanka. Based on international experience as well as predicted availability of cleaner fuels in the region (in countries from which Sri Lanka is likely to import refined products in the coming decade), suggest reasonable limits based on the likely level of air quality in the future in the major cities of Sri Lanka. CPC has specifically asked that the study cover in particular the use of MMT (which would entail a review of international literature) to boost octane by about 1 point.

[3] Analyse the impact of tightened fuel specifications and new limits imposed under two scenarios: (a) no change in the refining sector in Sri Lanka with growing demand to be met by imports; (b) implementation of the proposal to expand the refinery capacity from 50,000 b/d to 100,000 b/d, the details of which will be given by CPC to, and discussed with, the consultant (If the expansion plan is implemented, the earliest date by which the expanded refinery will come on stream will be 2005-2006). Also include in the analysis two scenarios for gasoline growth: (a) stagnation of demand for gasoline (because of increasing switch to diesel and LPG); (b) increasing gasoline demand at the expense of diesel demand growth on account of more balanced pricing of gasoline and diesel in the future.

[4] For each scenario, estimate the incremental cost (orders-of-magnitude calculations only are envisaged here) of meeting the proposed specifications and propose a feasible timetable.

Schedule and work plan

The consultant will start work in October 2001.

Action item	*Start*	*End*
1. Identification trip to Sri Lanka	10/2001	10/2001
2. Collection of all the necessary information	10/2001	10/2001
3. Preparation of draft report	11/2001	11/2001
4. Submission of draft report	11/15/2001	11/15/2001
5. Submission of final report acceptable to the Government of Sri Lanka incorporating comments	01/31/2002	01/31/2002

APPENDIX B - 3

Terms of Reference for Fiscal Policies on Fuels & Vehicles (International Consultant)

Background Information:

The government of Sri Lanka has obtained an IDF Grant from the World Bank to strengthen the institutional and policy framework for urban air quality management in Colombo. The overall objective of the proposed activity is to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions.

Institutional Arrangement

A project management unit established at the ministry of Forestry & Environment will implement the Project, and consultants should submit their reports to Dr. B.M.S. Batagoda, Project Director. The consultant will be provided space within the office. They can use facilities available at the project office such as computer, printer, photocopy machine and OHP.

The consultants are expected to work with two local counterpart officers and a local consultant during the consultancy period.

The program will consist of three components.

a *Vehicle emissions reduction* The grant will be used to strengthen the capacity of the Department of Motor Traffic, the Planning Unit of the Ministry of Transport, and the Central Environmental Authority for vehicle emissions control, and to assist in revising in-use vehicle emission standards, establishing an inspection and maintenance program, limiting the number of polluting vehicles on the road, awareness-raising, and exploring innovative partnership arrangements and financing mechanisms.

b *Gasoline and diesel quality improvement.* This component will facilitate policy decisions on implementing realistic, fiscally sound and socially beneficial plans for phasing out leaded gasoline, improving diesel quality and rationalising demand for these fuels which is currently distorted by a large price differential. In particular, the grant will be used to examine the feasibility of tightening gasoline and diesel quality standards; analyse fiscal, financial and public health implications of changes in fuel specifications and relative prices as well as the impact of these changes on low-income groups; and recommend possible options to the Government of Sri Lanka.

c *Fiscal Policies on Fuels and Vehicles.* Alternative options for pricing diesel and gasoline and levying duties on different vehicles will be examined, from the point of

view of long-term fiscal sustainability, impacts on households' welfare (expenditure) and decreasing most harmful vehicular emissions. While the activity addresses issues raised during discussions on components (a) and (b), it is proposed as a separate component because of different expertise and main counterpart agency required for its implementation

Components (b) and (c) have overlapping fiscal issues (fuel pricing and vehicle duties), which are covered under, separate terms of reference.

Scope of Fiscal Policies on Fuels & Vehicles and objectives

Fuel taxation and pricing have impacts, which cut across a number of sectors and issues. The price of gasoline is kept high in Sri Lanka to cross-subsidise other fuels, particularly diesel and kerosene. This in turn has led to owners of light-duty vehicles switching from gasoline to diesel, reducing an important source of revenue for CPC. Moreover, there is increasing evidence that diesel emissions are much more harmful than gasoline emissions, and hence increasing the share of diesel vehicles has an adverse impact on public health in urban areas. Increasing the price of diesel to stem this trend, however, would affect a number of sectors using diesel such as freight transport, agriculture and power generation. Further, unless the price of kerosene is raised at a comparable rate, there is a serious danger of a large-scale diversion of kerosene to diesel as seen in India, since a significant amount of kerosene can be added to diesel without affecting vehicle performance. On the other hand, if the price of kerosene is increased markedly to prevent this diversion, low income households currently using kerosene for such household needs as lighting and cooking may no longer be able to use as much kerosene, and be forced to cut back on lighting (which in turn would affect studying by school age children and other activities) or switch back to biomass for cooking, thereby exposing household members to significant levels of indoor air pollution. All these effects of inter-fuel pricing adjustments need to be taken into account in considering different policy options.

The consultant will

[1] Examine the current taxes and prices for relevant petroleum products (diesel, gasoline, and kerosene).

[2] Consider several options for reducing emissions from imported vehicles, including age limits, changing the duty structure (for example, by fuel type combined with vehicle weight; by age) or controlling emissions directly. Reductions in vehicle emissions should be evaluated from the point of view of impact on public health (e.g., exposure to PM10-- from primary emissions of PM10 and secondary sulphates and nitrates-- is of major concern). Analyse the fiscal impact of each as well as likely impact on emissions. Analysis of some options may need to be carried out in combination with fuel pricing measures from [3], as the ultimate impact on budget revenues and emissions are a function of demand for different vehicle categories which in turn depends on both relative prices of diesel and gasoline and differentiated vehicle duties.

[3] Evaluate transport fuel pricing policy and alternative options from the point of view of fiscal impact, reducing vehicle emissions, and impact on the welfare of the poor. Alternative options should include feasible options for reducing the gap between retail prices of diesel and gasoline, possibly in combination with alternative schemes of

imposing differentiated vehicle duties (see [2] and [4]). Household survey data should be used in conjunction with input-output matrix for this purpose. Options to be studied include (the combinations of) the following scenarios: (a) raising the price of diesel and lowering (or maintaining at the same level) the price of gasoline in different proportions to narrow the price gap; (b) different designs of a diesel tax, e.g. a tax refundable to bulk users, (c) keeping the price of kerosene comparable to the price of diesel; and (d) maintaining the current level of kerosene price but taking into account diversion of kerosene to the diesel sector as the price difference between the two fuels widens in estimating the fiscal impact. Conduct sensitivity analysis on the assumptions made.

[4] Examine the current tax structure (annual levies) on vehicles and alternative schemes to arrest the current trend of increasing share of diesel-fuelled light-duty vehicles;

[5] Summarise the findings in a form conducive to policy discussion.

Schedule and work plan

The consultant will start work in October 2001.

Action item	*Start*	*End*
1. Identification trip to Sri Lanka	10/2001	10/2001
2. Collection of all the necessary information	10/2001	10/2001
3. Preparation of draft report	11/2001	11/2001
4. Submission of draft report	12/15/2001	12/15/2001
5. Submission of final report acceptable to the Government of Sri Lanka incorporating comments	01/31/2002	01/31/2002

APPENDIX B - 4

Terms of Reference for Vehicle Emissions Reduction (Local Consultant)

The government of Sri Lanka (GOSL) has obtained an IDF grant from the World Bank to strengthen the institutional and policy framework for urban air quality management in Colombo. The overall objective of the proposed activity is to help institution and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to particles, lead and other pollutants in vehicle emissions. The local consultant will be procured to fulfill the following tasks, which would be the inputs to the international consultant to be procured under separate terms of reference. The local consultant should also work closely with the international consultant to coordinate the transfer of knowledge. As such, we recommended that some indication of time commitment be spelt out in the terms of reference. For example, the initial data collection may take 2 months, the local consultant should be available during the four trips made by the international consultant, and put in the equivalent of 2 days a week during the rest of the execution of this component. This will amount to 7.6 months over the course of 12 months.

1) Collect time series data for 20 year period of the active vehicle fleet data with characteristics, (category and fuel types, two strokes motor cycles and three wheelers, age distribution, country origin, engine capacities) type of valve seat (soft or hard, for the purpose of determining the need for lubricant additives after gasoline lead elimination), and octane requirements (as specified by vehicle manufactures);

2) Analyze and forecast future vehicle fleet and its characteristics on three economic scenarios forgiving three specific GDP scenarios with indication of the relationship between GDP and vehicle fleet population growth, such as income elasticity etc., which will be used by the international consultants;

3) Collect data on registered authorized motor garages to see how many authorized garages there are for the purpose of repairing vehicles? This should be restricted to Colombo only. This data will use to prepare an inventory in order to feed the information to the international consultant to formulate programme for proper vehicle inspection and maintenance programme;

4) Study and prepare a document presenting record keeping procedure, vehicle registration system and annual licensing system of the Department of Motor Traffic enabling international consultant to develop a record keeping procedure;

5) Document current vehicle import policy of GOSL;

6) Prepare a list of potential trainees for the pilot training programme of the mechanics with the assistance of main vehicle manufactures (e.g. Bajaj auto for three wheelers) and Central Environmental Authority;

7) Collect data on fleet characteristics of two stroke engine vehicles, in addition to the data collected under the item 1 providing detail count of three wheelers and two wheelers and, consumption of 2T (if there any addictive please include them) oils for last ten years;

8) Collect data through a statistically selected sample, in relation to fuel efficiency of the vehicles representing the operational fleet in the country. Consultant may get assistants through hired enumerators. The consultant should arrange field survey at refueling stations asking drivers how much they purchase and how many kilometers they expect to be able to run on the quantity purchased? This survey be confined to Colombo;

9) Analyze data collected under items 8 for the use of international consultant for his work;

10) Collect and summarize all the air quality related work in Sri Lanka related to the objective of this grant before the arrival of international consultant and make comments which may be useful for the international consultant;

11) Assist the international consultant to organize training programs and other workshops;

12) Facilitate the transfer of knowledge from the international consultant to local counterparts. Coordinate various activities in this component by acting as an intermediary between the international consultant and the transport ministry, and liaising with all the key stakeholders etc.

Based on these TOR, assuming a local consultant to put in 7.6 months and four assistants for the field survey of 1 month each, it appears that a more appropriate budget would be on the order of $8,100 (=$1,000x 7.6 + Rs. 10,000 x 4) and not $20,000 as shown in the budget.

APPENDIX B - 5

Terms of Reference for Fiscal Policies on Fuels & Vehicles (Local Consultant)

Background

The government of Sri Lanka has obtained an IDA Grant from the World Bank to strengthen the institutional and policy framework for urban air quality management in Colombo. The overall objective of the proposed activity is to help develop institutions and policies needed to reverse the deterioration in Colombo's air quality and its accompanying adverse health effects from exposure to fine particles, lead and other vehicle emissions.

The program will consist of three components.

(a) *Institutional development* The grant will support strengthening of the current institutional and organizational capacity for establishing environmental standards, monitoring and enforcing the standards.

(b) *Vehicle emissions reduction* The grant will be used to strengthen the capacity of the Department of Motor Traffic, the Planning Unit of the Ministry of Transport, and the Central Environmental Authority for vehicle emissions control, and to assist in revising in-use vehicle emission standards, establishing an inspection and maintenance program, limiting the number of polluting vehicles on the road, awareness-raising, and exploring innovative partnership arrangements and financing mechanisms.

(c) *Gasoline and diesel quality improvement.* This component will facilitate policy decisions on implementing realistic, fiscally sound and socially beneficial plans for phasing out leaded gasoline, improving diesel quality and rationalizing demand for these fuels which is currently distorted by a large price differential. In particular, the grant will be used to examine the feasibility of tightening gasoline and diesel quality standards; analyze fiscal, financial and public health implications of changes in fuel specifications and relative prices as well as the impact of these changes on low-income groups; and recommend possible options to the Government of Sri Lanka.

Components (b) and (c) have overlapping fiscal issues (fuel pricing and vehicle duties), which are covered under, separate terms of reference given below.

Main issues

Fuel taxation and pricing have impacts, which cut across a number of sectors and issues. The price of gasoline is kept high in Sri Lanka to cross subsidize other fuels, particularly diesel and kerosene. This in turn has led to owners of light duty vehicles switching from gasoline to diesel, reducing an important source if revenue for CPC. Moreover, there is increasing evidence that diesel emissions are much more harmful than gasoline emissions,

and hence increasing the share of diesel vehicles has an adverse impact on public health in urban areas. Increasing the price of diesel to stem this trend, however, would affect a number of sectors using diesel such as freight transport, agriculture and power generation. Further, unless the price of kerosene is raised at a comparable rate, there is a serious danger of a large scale diversion of kerosene to diesel as seen in India, since a significant amount of kerosene can be added to diesel without affecting vehicle performance.

On the other hand, if the price of kerosene is increased markedly to prevent this diversion, low income households currently using kerosene for such household needs as lighting and cooking may no longer be able to use as much kerosene, and be forced to cut back on lighting (which in turn would affect studying by school age children and other activities) or switch back to biomass for cooking, thereby exposing household members to significant levels of indoor pollution. All these effects of inter fuel pricing adjustments need to be taken into account in considering different policy options.

Objectives:

The consultant will,

1. Study the impact of increase in fuel prices on freight and passenger transport sectors.
2. Study the impact of increase of fuel prices on poor households.
3. Use household survey data and input output matrix for the purpose of these calculations.
4. Discuss the outcome with International consultants and work with them where necessary

The local consultant will perform the following tasks, which will provide inputs to the work of international consultants, to be procured under separate terms of reference.

1. Collect data on prices and taxes for all relevant petroleum products- gasoline, auto diesel, kerosene, naptha, fuel oil, LPG, over the last three years. Record all the prices/tax changes during these years.
2. Describe the tax structure for petroleum fuels (including GST, excise duties, etc.) separately for domestic and import products, if needed.
3. Review tax policies for imported petroleum products versus domestic products.
4. Collect data and review policies on vehicle duties (import duties and registration fees), by type, age, fuel, user, etc., including exceptions for specific users.
5. Locate, obtain (in the electronic format) and describe the most recent input/output matrix.
6. Obtain the most recent household expenditure survey (SLIS 2000) and describe relevant items (questions on expenditure on fuels, vehicles, electricity, and other good/service prices of which are affected by fuel prices).
7. Work with the international consultant on fiscal issues, address his/her comments/needs, and help with the identification and analysis of any additional data that international consultant might request.
8. Consultants should make close collaboration with the Ministry of finance, fiscal policy division and Air Resource Management Center.

APPENDIX B - 6

Terms of Reference for the Legal Consultant for development of a legal framework for the implementation of Vehicle Emission Standards in Sri Lanka

The Consultant shall undertake the following tasks in close consultations with the Commissioner of Motor Traffic, Secretary to the Ministry of Transport, Highways & Civil Aviation and partners of the Air Resource Management Centre.

1) Review the legal provisions under National Environment Act with respect to implementation of vehicle emission standards at national, provincial and local level.

2) Review legal provisions for the implementation of regulations under National Environment Act in a particular province or in a local authority area, without implementing them nationwide.

3) Review the legal provisions under the Motor Traffic Act (Chapter-203) with respect to implementation of vehicle emission standards in a province or in a local authority area, as a pilot project without implementing them nationwide.

4) Review the constitutional provisions on devolutions of power with respect to implementation of vehicle emission standards in a province or in a local authority area, particularly focussing on the role of central government and the role of provincial council in the implementation of vehicle emission standards.

5) Review the local government and provincial council legislations with respect to the implementation of vehicle emission regulations under the national regulatory framework.

6) Develop appropriate legal framework for the implementation of vehicle emission standards as a pilot project in a selected province under national regulatory framework.

7) Develop legal and financial framework for the preparation of Request for Proposals (RFP) for selecting private sector agencies for setting up of vehicle emission testing centres.

The Consultancy should be completed within a month. You are free to complete this task with the help of any suitable experts.

Appendix C

Presentation Materials of Training Programs

Appendix C - 1

Technician Training Program on Diesel Vehicle Emission

Sri Lanka Urban Air Quality Management
Vehicle Emission Reduction Component

Training Workshop on
Causes and Diagnosis of High Diesel Smoke

Presented at
Automotive Engineering Technical Institute
Colombo, Sri Lanka
November 27, 2002



Christopher S. Weaver, P.E.
Engine, Fuel, and Emissions Engineering, Inc.
Sacramento, California

Workshop Overview

- What is diesel smoke?
- How smoke is measured
- Diesel smoke levels in Colombo
- Smoke opacity inspection pilot program
  - role of cooperating diesel repair shops
- Common causes of high diesel smoke
- Procedure for smoke diagnosis

What is Diesel Smoke?

- **Black smoke: fine particles of black carbon (soot) formed in diesel combustion**
  - **Diesel combustion produces large amounts of soot**
  - **Normally, almost all the soot formed is burned up later in the combustion process**
  - **If something interferes, soot survives to be emitted in exhaust**
    - **too little air for amount of fuel**
    - **poor mixing between air and fuel**
    - **too little time for soot combustion to be completed**
- **Gray/white smoke: fine droplets of liquid such as lubricating oil, fuel, or coolant**
- **Particulate matter (smoke) is one of the most dangerous air pollutants**
  - **cancer** - **heart disease**
  - **lung disease** - **colds, flu, pneumonia, etc.**

Smoke Measurements

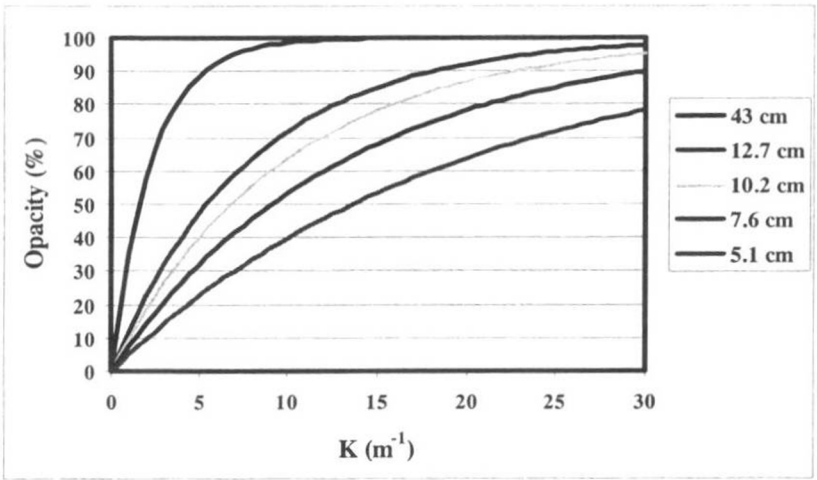
- **Light absorbtion follows the Beer-Lambert Law**

  Opacity (%) = 100 (1 - exp (-K L))

  K = index of absorbtion (density) of smoke (m^{-1})

  L = Path length of light through the smoke (m)
- **Smokemeters measure light absorption, and afterwards convert to "K"**
- **Measured opacity depends on the path length**
  - **Europe - standard "Hartridge" distance of 43 cm**
  - **SAE (U.S.) - diameter of exhaust pipe, from 5.1 to 12.7 cm (2 to 5 inches)**
- **We will use the "K" index to avoid confusion caused by differing path lengths**
- **Present Sri Lankan regulations specify both "K" and opacity (based on Hartridge path length)**
  - **3.22 m^{-1} = 75% opacity under load**

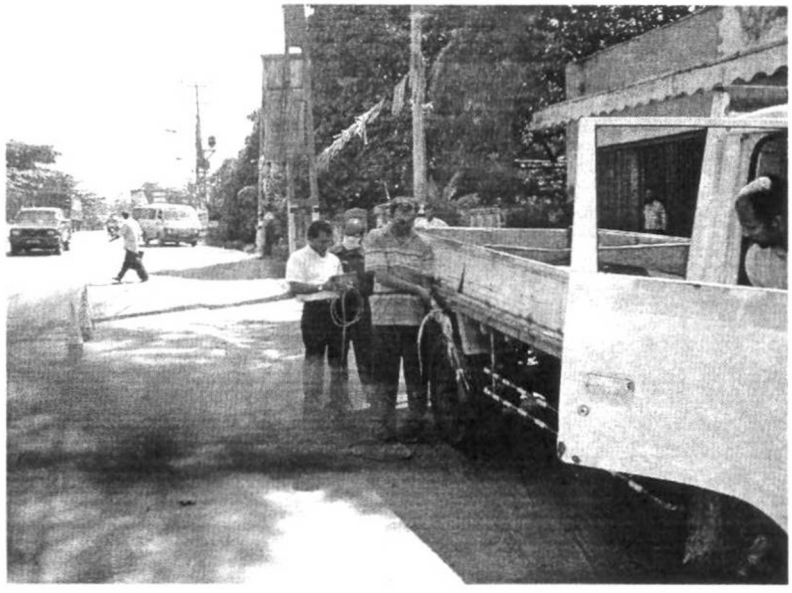
Opacity Vs. "K" for Different Path Lengths



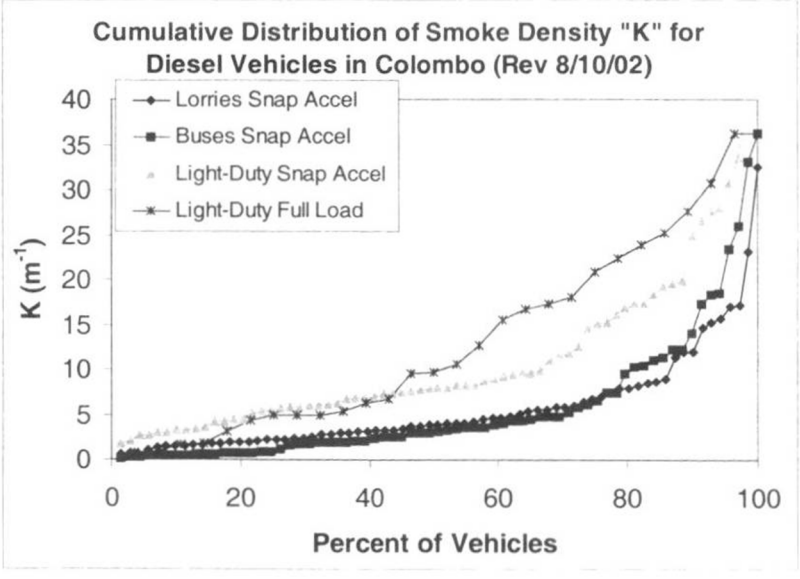
Smoke Measurements in Colombo



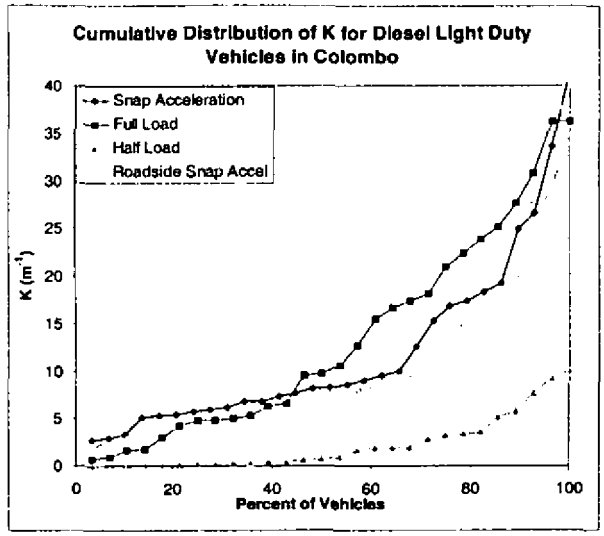
Smoke Measurements in Colombo



Diesel Smoke Levels in Colombo



Diesel Smoke Levels in Colombo



Smoke Opacity Inspection Pilot Program

- **Measure snap acceleration smoke opacity of vehicles stopped at roadside test locations**
- **Vehicles with "K" value greater than 8 will be cited and referred to cooperating repair shops**
- **Shops diagnose and repair causes of smoke**
  - **Record diagnosis, repairs, and repair costs on data form**
- **Vehicle returns to test location to be retested**
- **Afterward, we will assess**
  - **main causes of high smoke**
  - **effectiveness of inspection and repair program to reduce smoke**
  - **average costs and average smoke reduction per vehicle**

Common Causes of High Black Smoke

- Too much fuel for the amount of air in the combustion chamber
  - Tampering with maximum fuel limit
  - Dirty air filter
  - Air ducts constricted or damaged
  - Worn-out or damaged turbocharger
  - Acceleration smoke limiter improperly set (T/C engines only)
- Poor mixing between fuel and air
  - Injection nozzles clogged with deposits
  - Worn-out injection nozzles
  - Worn-out injection pump
- Retarded fuel injection
  - Injection pump misaligned
  - Injection pump worn out

Common Causes of High Gray or White Smoke

- Smoke from lubricating oil
  - Leaking oil seals on exhaust or intake valves
  - Worn-out or damaged piston rings / cylinder liner
  - Leaking turbocharger oil seals
- Smoke from fuel
  - Cold engine
    - thermostat malfunction
  - Low fuel cetane number
  - Inadequate compression
  - Incorrect fuel injection timing
- Coolant leaking into cylinder or exhaust

Diesel Smoke Diagnosis Procedure

- Check the color of smoke and when it occurs
  - Snap acceleration test
    - Note smoke density at peak, and stabilized (full RPM no load)
  - Observe smoke while vehicle is driving on the road
    - Is there visible smoke at part load?
    - Heavy or moderate smoke on hard acceleration?
    - Short "puff" at start of acceleration or long plume?
    - Smoke color - gray or black?
- Check air cleaner (restriction indicator or visual check) and replace if dirty
- Check fuel pump adjustment seals

Likely Causes of High Smoke

- Gray smoke
  - Check engine compression
    - If OK, problem is probably oil seals - valve or turbocharger
    - If not, problem is probably piston rings / liner worn out
- Thick black smoke on acceleration / little or no smoke at part load
  - Usually means too much fuel for air in combustion chamber
  - Short puff (on turbo engine) - check acceleration smoke limiter
  - Check for restrictions in air intake system
  - Check maximum fuel limit on injection pump
  - Check turbo boost pressure (on turbocharged engine)

Likely Causes of High Smoke

- **Thick black smoke on acceleration / heavy to moderate smoke at part load**
  - Usually means air-fuel mixing is poor
  - Check injection nozzles for deposits and correct opening pressure
    - replace if necessary
  - Check injection pump timing
  - Test injection pump
    - rebuild / replace if necessary

Appendix C - 2

Technician Training Program on Two-Stroke Motorcycles and Three-Wheelers Emission

Sri Lanka Urban Air Quality Management
Vehicle Emission Reduction Component

Workshop on
Pilot Emissions Inspection and Repair Program for Two-Stroke Motorcycles and Three-Wheelers

Colombo, Sri Lanka
December 4, 2002



Christopher S. Weaver, P.E.
Engine, Fuel, and Emissions Engineering, Inc.
Sacramento, California

Workshop Overview

- **Air pollution from motor vehicles**
  - **Smoke and particulate matter (PM)**
  - **Gaseous emissions (HC, CO, NOx)**
- **Smoke and gaseous emissions from petrol vehicles**
  - **Emission levels of two-stroke three-wheelers and MC in Colombo**
  - **Common causes of high emissions**
- **Plans for roadside emission checks and repairs**

Smoke and Particulate Matter

- **Particulate matter (smoke) is one of the most dangerous air pollutants**
  - **cancer** - **heart disease**
  - **lung disease** - **colds, flu, pneumonia, etc.**
- **Black smoke: fine particles of black carbon (soot) formed by combustion under rich conditions (excess fuel)**
  - **Primarily due to diesel vehicles**
  - **Petrol vehicles form soot only if air-fuel mixture is seriously maladjusted**
- **Gray/white smoke: fine droplets of liquid such as lubricating oil, fuel, or coolant**
  - **Some white smoke is normal for 2-stroke petrol engines**
  - **Excessive 2-T smoke is a main target of this program**

Gaseous Emissions

- **Unburned hydrocarbons (HC)**
  - **Contribute to ozone smog through reaction with NOx**
  - **Include many toxic and carcinogenic compounds such as benzene and 1,3 butadiene**
  - **2-T engines have very high HC emissions due to breakthrough of unburned fuel/air mixture to exhaust during scavenging**
    - **species composition of unburned HC resembles vaporized gasoline**
- **Carbon monoxide (CO)**
  - **Produced by partial combustion of fuel under rich conditions**
  - **Poisonous, interferes with blood oxygen transport mechanism**
  - **Headache, dizziness, reduced mental function, increased risk of heart attack, death from prolonged exposure**
- **Oxides of nitrogen (NOx)**
  - **Not of major concern for 2-T engines**

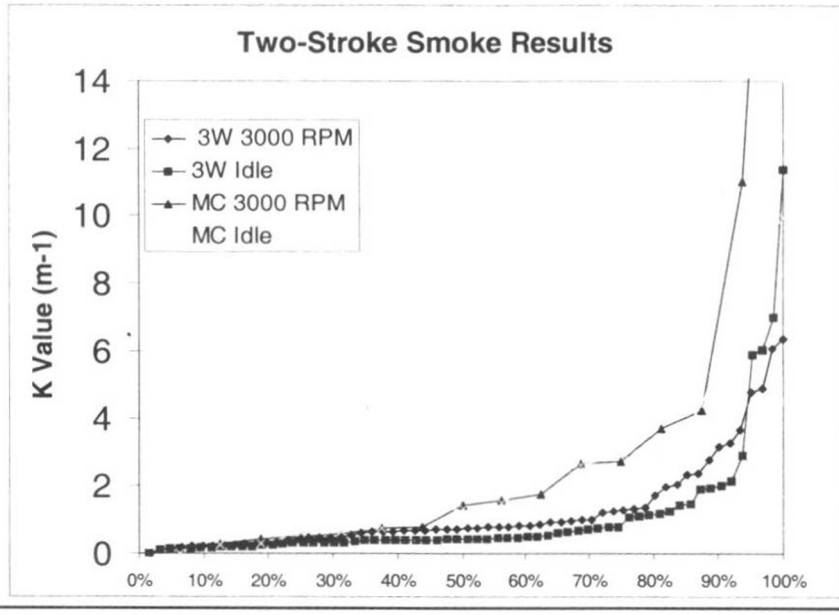
Smoke Measurements

- Light absorption follows the Beer-Lambert Law
  Opacity (%) = 100 (1 - $e^{(-K L)}$)
  K = index of absorbtion (density) of smoke (m^{-1})
  L = Path length of light through the smoke (m)
- Smokemeters measure light absorption (opacity)
  - Afterwards convert to "K" = - (ln (1 - Op/100)) / L
- Measured opacity depends on the path length
- Smoke measurements for this program based on path length of 0.061 meters (diameter of adaptor tube)
- Measure maximum smoke opacity
  - idle
  - approx. 3000 RPM

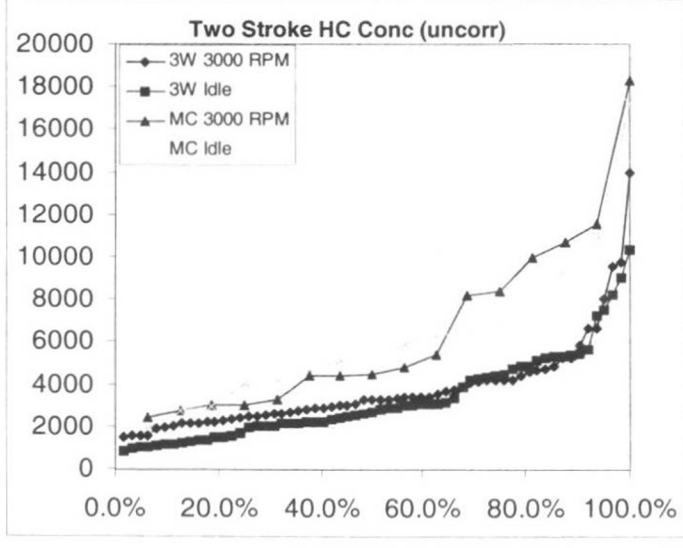
Test Procedures for Three-Wheelers and Motorcycles

- Measure HC, CO, CO2, and Oxygen using Horiba MEXA 554 J Gas Analyzer
  - Idle
  - 3500 RPM
- Measure smoke opacity using Wager 6500 smokemeter with 61 mm adaptor tube
  - idle
  - 3500 RPM
- Initial survey omitted oxygen measurement
  - difficult to account for dilution due to air leaks and exhaust pulsation
- Initial survey estimated RPM by "ear" instead of using tachometer

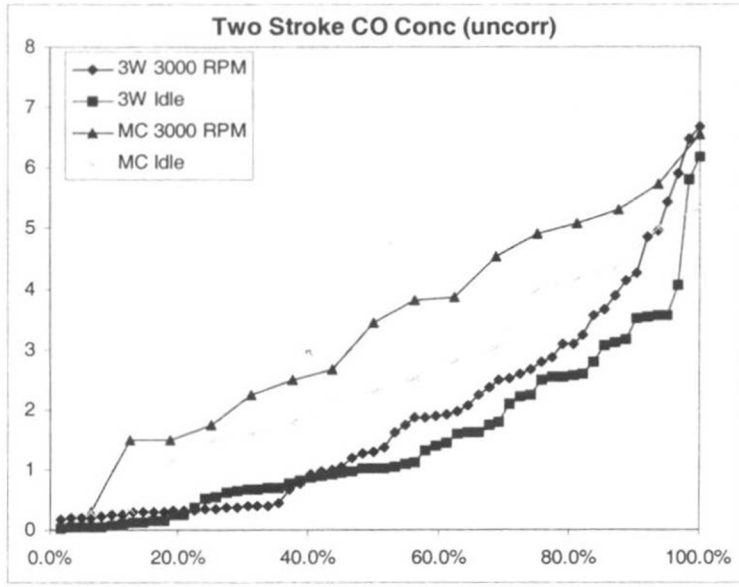
2-T Smoke Levels in Colombo



2T HC Levels in Colombo



2T CO Levels in Colombo



Common Causes of High 2T Smoke

- **Too much lube oil**
  - **overmixing of oil with fuel**
  - **maladjustment of auto-lube pump on engines so equipped**
  - **attitude "some is good, so more is better"**
- **Wrong type of lube oil (engine oil instead of 2-T oil)**
- **Ignition problems causing misfire**
  - **spark plug**
  - **contact breaker point**
  - **ignition cable**
- **Incorrect air-fuel ratio causing misfire**
  - **mis-set or dirty carburetor**
  - **clogged air filter**
- **Clogged silencer**

Common Causes of High HC and CO in 2T Vehicles

- Ignition problems causing misfire or poor combustion
- Incorrect air-fuel ratio
  - mis-set or dirty carburetor
  - clogged air filter
- Excessive backpressure due to clogged exhaust
  - misfire or poor combustion
- Engine design (porting, scavenging) causes high HC in some "racing" motorcycle engines

2T Inspection Pilot Program

- Measure emissions and smoke opacity of vehicles stopped at roadside test locations
- Vehicles that exceed provisional emission standards are offered simple diagnosis and repairs at roadside
  - carburetor adjustment
  - replace fuel with clean fuel containing right amount of 2T oil
- Vehicles that still fail (or refuse repairs) receive prohibition notices from Dept. of Motor Traffic
  - Referred to cooperating shops
  - Record diagnosis, repairs, and repair costs on data form
- Vehicle returns to test location to be retested
- Afterward, we will assess
  - main causes of high emissions
  - effectiveness of inspection and repair program
  - average costs and average emission reduction per vehicle

Appendix C - 3

Training Program on Vehicle Inspection and Maintenance Program for Examiners and Traffic Police Officers

Sri Lanka Urban Air Quality Management
Vehicle Emission Reduction Component

Training Workshop on
Motor Vehicle Emissions Inspection

Presented to
Motor Vehicle Examiners
Colombo, Sri Lanka
November 30, 2002



Christopher S. Weaver, P.E.
Engine, Fuel, and Emissions Engineering, Inc.
Sacramento, California

Workshop Overview

- **Air pollution from motor vehicles**
  - **Smoke and particulate matter (PM)**
  - **Gaseous emissions (HC, CO, NOx)**
- **Diesel smoke**
  - **Measurement**
  - **Smoke levels of vehicles in Colombo**
  - **Common causes of high diesel smoke**
- **Smoke and gaseous emissions from petrol vehicles**
  - **Measurement**
  - **Emission levels of three-wheelers in Colombo**
  - **Common causes of high emissions**
- **Designing an effective vehicle emissions inspection program**
- **Role of motor vehicle examiners in vehicle emissions inspection**
- **Calibration and use of emission measurement equipment**

Smoke and Particulate Matter

- **Particulate matter (smoke) is one of the most dangerous air pollutants**
  - cancer - heart disease
  - lung disease - colds, flu, pneumonia, etc.
- **Black smoke: fine particles of black carbon (soot) formed by combustion under rich conditions (excess fuel)**
  - Diesel combustion produces large amounts of soot, but almost all the soot formed is burned later in the combustion process
  - If something interferes, soot survives to be emitted in exhaust
    - too little air for amount of fuel
    - poor mixing between air and fuel
    - too little time for soot combustion to be completed
  - Petrol vehicles form soot only if air-fuel mixture is maladjusted
- **Gray/white smoke: fine droplets of liquid such as lubricating oil, fuel, or coolant**
  - Normal for 2-stroke petrol engines, abnormal for others

Gaseous Emissions

- **Unburned hydrocarbons (HC)**
  - Contribute to ozone smog through reaction with NOx
  - Include many toxic and carcinogenic compounds such as benzene and 1,3 butadiene
- **Carbon monoxide (CO)**
  - Produced by partial combustion of fuel under rich conditions
  - Poisonous, interferes with blood oxygen transport mechanism
  - Headache, dizziness, reduced mental function, increased risk of heart attack, death from prolonged exposure
- **Oxides of nitrogen (NOx)**
  - NO formed from atmospheric N_2 and O_2 at high temperature
  - Oxidizes to NO_2 and nitrate particles in the atmosphere
  - Reacts with HC to form ozone smog

Diesel Smoke

- Diesel smoke measurements
- Smoke levels of diesel vehicles in Colombo
- Common causes of high diesel smoke

Diesel Smoke Measurements

- Light absorbtion follows the Beer-Lambert Law
  Opacity (%) = $100\ (1 - e^{(-K\ L)})$
  K = index of absorbtion (density) of smoke (m^{-1})
  L = Path length of light through the smoke (m)
- Smokemeters measure light absorption (opacity)
  - *Afterwards convert to "K" = - (ln (1 - Op/100)) / L*
- Measured opacity depends on the path length
  - Europe - standard "Hartridge" distance of 43 cm
  - SAE (U.S.) - diameter of exhaust pipe, from 5.1 to 12.7 cm (2 to 5 inches)
- Use of "K" index is recommended to avoid confusion caused by differing path lengths
- Present Sri Lankan regulations specify both "K" and opacity (based on Hartridge path length)
  - 3.22 m^{-1} = 75% opacity under load

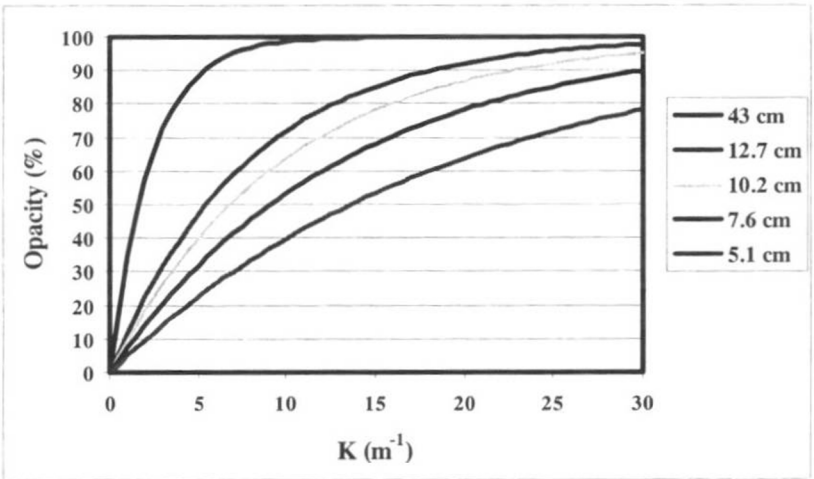
Diesel Smoke Test Procedures

- **Steady-state (recommended, but requires dynamometer)**
  - **Full load**
    - **accelerator pedal fully depressed**
    - **dyno set to maintain constant speed**
  - **One-half load**
    - **dyno set to maintain same constant speed**
    - **release accelerator pedal until the dynamometer torque is one-half the value measured in full-load test**
- **Snap acceleration**
  - **Less reliable than steady-state tests**
  - **Useful for roadside testing and control of transient smoke from turbocharged vehicles**

Snap Acceleration Test Procedure (SAE Recommended Practice J1667)

- **With transmission in neutral, slowly raise engine RPM until maximum speed governor comes in**
  - **If maximum speed governor does not come on, DO NOT TEST (but issue citation requiring repair of governor)**
- **Snap acceleration**
  - **Start with engine at idle in neutral**
  - **Rapidly depress accelerator to the floor**
  - **Hold accelerator down until engine reaches governor speed and remains there for 2-3 seconds**
  - **Release accelerator and wait at least 5 seconds until the engine returns to idle**
- **Test procedure**
  - **Perform at least 3 snap accelerations before measuring to clear out any accumulated soot**
  - **Measure maximum smoke opacity during 3 snap accelerations and average (measurements should agree within 10% opacity)**

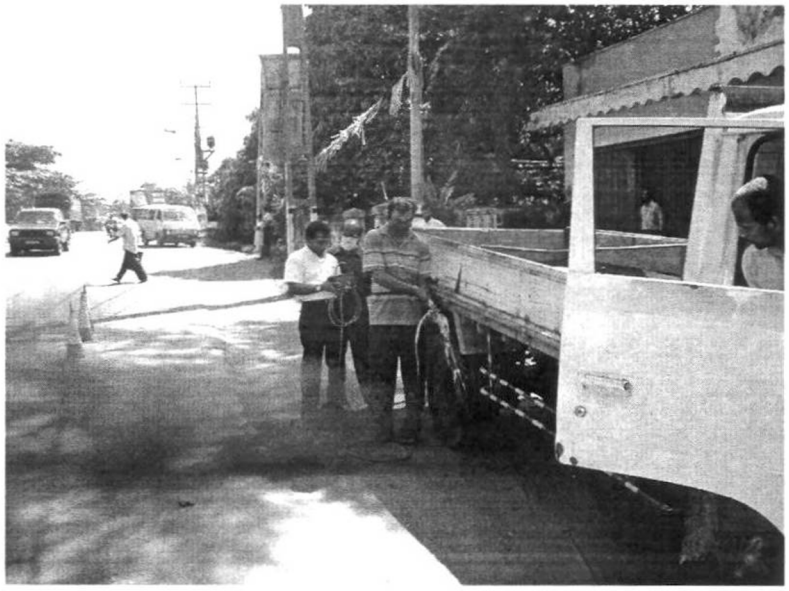
Opacity Vs. "K" for Different Path Lengths



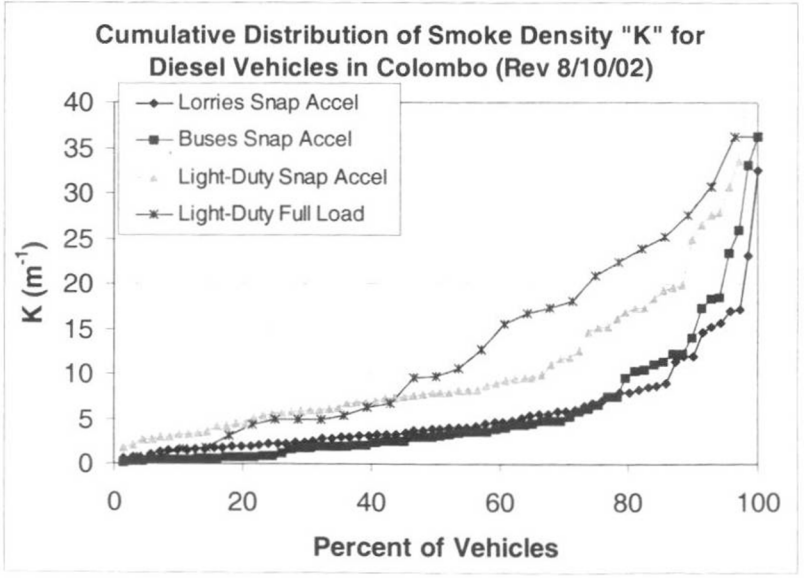
Smoke Measurements in Colombo



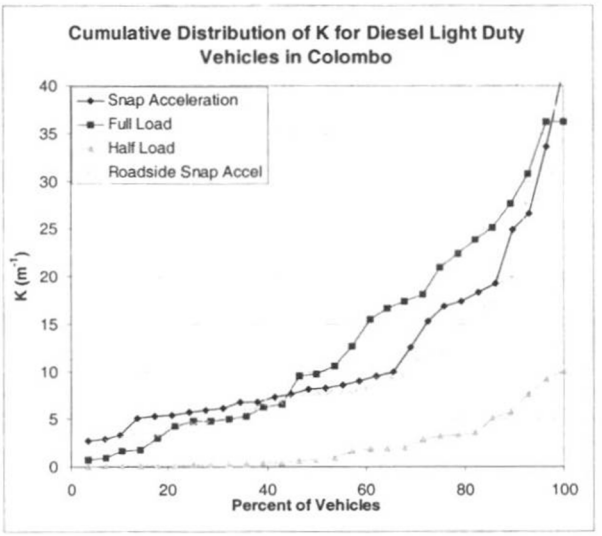
Smoke Measurements in Colombo



Diesel Smoke Levels in Colombo



Diesel Smoke Levels in Colombo



Smoke Opacity Inspection Pilot Program (Under Way)

- Measure snap acceleration smoke opacity of vehicles stopped at roadside test locations
- Vehicles with "K" value greater than 8 are cited and referred to cooperating repair shops
- Shops diagnose and repair causes of smoke
  - Record diagnosis, repairs, and repair costs on data form
- Vehicle returns to test location to be retested
- Afterward, we will assess
  - main causes of high smoke
  - effectiveness of inspection and repair program to reduce smoke
  - average costs and average smoke reduction per vehicle

Common Causes of High Black Smoke

- Too much fuel for the amount of air in the combustion chamber
  - Tampering with maximum fuel limit
  - Dirty air filter
  - Air ducts constricted or damaged
  - Worn-out or damaged turbocharger
  - Acceleration smoke limiter improperly set (T/C engines only)
- Poor mixing between fuel and air
  - Injection nozzles clogged with deposits
  - Worn-out injection nozzles
  - Worn-out injection pump
- Retarded fuel injection
  - Injection pump misaligned
  - Injection pump worn out

Common Causes of High Gray or White Smoke

- Smoke from lubricating oil
  - Leaking oil seals on exhaust or intake valves
  - Worn-out or damaged piston rings / cylinder liner
  - Leaking turbocharger oil seals
- Smoke from fuel
  - Cold engine
    - thermostat malfunction
  - Low fuel cetane number
  - Inadequate compression
  - Incorrect fuel injection timing
- Coolant leaking into cylinder or exhaust

Smoke and Gaseous Emissions from Petrol Vehicles

- White/gray smoke from lubricating oil
  - Some smoke is normal for two-stroke engines
  - Excess smoke results from using the wrong oil, using too much of it, or both
  - White/gray smoke from four-stroke engines indicates maintenance problem
- Carbon monoxide
  - Some CO is normal for petrol combustion
  - High CO levels > ~2% indicate maladjusted fuel mixture
- Hydrocarbons
  - Normal 4-stroke HC level is < 500 ppm
  - Two-strokes have very high HC (3000 - 18000 ppm) due to flow-through of unburned mixture during scavenging
  - Misfire, poor combustion increase HC emissions from two-strokes and four-strokes

Measuring Emissions from Petrol Vehicles

- Emissions measured
  - Smoke opacity (mostly for two-stroke vehicles)
  - Gaseous pollutant concentration
    - advanced systems can measure mass emissions of gaseous pollutants
- Chassis dynamometer method is preferred
  - part-load steady state works OK for older technologies
  - realistic transient driving cycle (e.g. I/M 240) preferred for advanced control technologies (Euro II+)
- Two-speed idle (idle and 2500 rpm / no load)
  - Poor correlation with in-use emissions, but can identify grossly maladjusted air-fuel mixture and misfire problems
  - Useful as a roadside supplement to chassis dynamometer test
  - Use 3500 rpm for motorcycles and three-wheelers

Petrol Vehicle Emissions in Colombo

- On-road surveys of autos and two-stroke three-wheelers / motorcycles
  - Two-speed idle method
    - Gaseous only for autos
    - Gaseous and smoke opacity for two-stroke MC/3W
- Qualitatively
  - Many autos had very high CO (rich mixture / wasting fuel)
  - Smoke and HC from 3W less than from MC
  - 3W smoke levels linked to type of oil used
    - high smoke due to use of 4-stroke oil in place of 2T oil
- Data still under analysis

Designing an Effective Vehicle Emissions Inspection Program

- High-volume, test-only inspection centres
  - Test-and-repair in private garages doesn't work
- Privately-operated inspection centres under government contract or permit and with close government supervision
  - Capital and operating costs (including supervision) recovered through inspection fees
  - Preferably multiple contractors, to allow termination of corruptor incompetent ones
- Emission testing using chassis dynamometers
- Link periodic inspection to vehicle registration
- Counterfeit-resistant (e.g. hologram) emissions certificates and dated window stickers
- Supplement periodic inspections with targeted on-road checks

Role of Motor Vehicle Examiners in Vehicle Emissions Inspection

- **Carry-out on-road emission checks to supplement periodic inspection**
  - Verify current registration and emissions sticker
  - Check actual emissions performance using roadside tests
    - especially important for diesel and two-stroke vehicles
- **Monitor performance and accuracy of private contractors performing periodic inspections**
  - "Overt" checks for proper records, calibration frequency, corred inspection procedures, operating hours
  - "Covert" checks of inspection accuracy/honesty using undercover vehicles
  - Continuous monitoring via CCTV

Calibration of Emission Measurement Equipment

- **Wager 6500 Smokemeter**
  - "Zero" opacity level set automatically when unit is turned on
  - Put an opaque object in the beam to check 100% opacity level
  - Opacity calibration chip (~37% opacity) provided with unit
    - check daily or in case of doubt
    - protect chip from light, which causes fading
- **Horiba MEXA 554J Exhaust Gas Analyzer**
  - "Zero" set automatically from atmospheric air each 1/2 hour
    - zero timer shows time remaining
  - "Span" calibration using pressurized cans with known gas concentration
    - zero first
    - select span gas calibration on menu
    - inject span gas into calibration gas port
    - follow menu instructions

Demonstration of Smokemeter and Gas Analyzer Use

Appendix C - 4

Training Program on Vehicle Emission Testing Equipments for Equipment Monitoring and Verification Officers

Measurement of Vehicular Emissions

Presented By
Thusitha Sugathapala

Thermo-Fluids & Energy Group
Department of Mechanical Engineering
University of Moratuwa

CONTENT

- Background
- Vehicular Emissions
- Emission Testing
- Testing Equipments
- Vehicle Emission Measurements in Colombo

1. BACKGROUND

1.1 Transport and Environment:

- **Transport: A Prime requirement of human society**
- **Development of the Transport sector**
  - **Extensive use of fossil fuel**
  - **Toxic and hazardous byproducts & emissions**
    - **Urban Air Pollution**
    - **Acid Rains**
    - **Climate Change**

1.2 Modes of Transport:

- **Road** - **Main Mode**
- **Aviation**
- **Railway**
- **Marine Vessels**

1.3 Engine Technology of Road Vehicles:

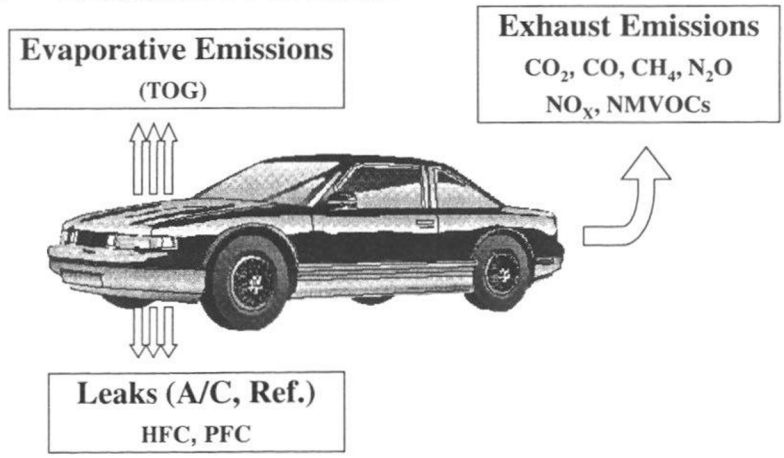
- **Reciprocating Internal Combustion (IC) Engines**

1.4 Classification of IC Engines:

- **Fuel**
  - **Gasoline** - Small Engines
  - **Diesel Oil** - Most Versatile
  - **Natural Gas** - Cleanest
- **Method of Ignition**
  - **Compression Ignition (CI)** - Diesel
  - **Spark Ignition (SI)** - Gasoline
- **Combustion Cycles**
  - **Two Strokes** - Higher Power to Weight Ratio
  - **Four Strokes** - More Efficient, Low Emissions

2. VEHICULER EMISSIONS

2.1 Emission Processes:



2.2 Exhaust Emissions:

- **Smoke and Particulate Matter**

  White smoke - Liquid particulate

  Blue smoke - Partially burned lub-oils

  Black smoke - Agglomerated carbon particles (soot)

- **Nitrogen Oxides (NO_X)**

  - Due to Thermal NO_X, Fuel NO_X (at high temperature)

- **Total Organic Compounds (TOC)**

  - TOC contains unburned or partially burned HCs and depends on combustion efficiency

2.2 Exhaust Emissions (Cont..):

- **Carbon Monoxide (CO)**

  - CO emission is mainly due to incomplete combustion

- **Sulfur Oxides (SO_X)**

  - SO_X emission is due to sulfur content in the fuel

  - Contributes to corrosion of engine

  - Contribute to PM_{10} and visibility reduction through formation of sulfate

- **Carbon Dioxide (CO_2)**

  - Due to complete combustion of fuel carbon

2.3 Categorization of Vehicles for Emissions:

- **Vehicle Type**
  - Passenger Cars
  - Duel Purpose Vehicles (Vans, Pickups)
  - Heavy Duty Vehicles (Buses, Lorries)
  - Two Wheelers, Three Wheelers
- **Fuel Type**
  - Gasoline
  - Diesel Oil
  - NG, LPG, Bio-Fuels
- **Gross Vehicle Weight**
- **Level of Emission Control Technique**

2.4 Emissions Control Measures:

- **New Vehicles**
  - ⊗ Advanced Technologies
    - Fuel Injection
    - Exhaust Gas Re-circulation (EGR)
    - Catalysts
    - Secondary Air Injection
    - Swirl Chamber Concepts
- **In-Use / Older Vehicles**
  - ⊗ The major source of emissions
  - ⊗ Strategies
    - Inspection &Maintenance
    - Retrofit
    - Accelerated Retirement
    - Alternative Fuel Conversion
- **Fuel Quality**

2.5 Vehicle Fleet

- **Road Vehicles:**

Vehicle Class	Active vehicle Fleet (Predicted)	Total registered vehicle fleet according to RMV
Motor Cycles	611795	834398
Cars	147297	232973
Three Wheelers	91997	102028
Dual Purpose Vehicles	131804	135608
Buses	32546	64970
Lorries	120312	171892
Land Vehicles	104625	128228
Total	1240376	1670097

- **Railway - 200 diesel locomotives and 46 power sets**

3. EMISSION TESTING

3.1 Vehicle Inspection & Maintenance Program:

- Technically Sound
- Socially Acceptable
- Not too Costly

3.2 Tests Procedure:

- Relatively Simple
- Short Duration
- Low Cost
- Reliable Results

3.2 Tests Procedure (Cont..)

- Engine operating modes during the test
- Type of emission measurements
- Pollutants covered
- Required pre-conditioning period
- Test duration
- Necessary test equipment.

3.3 Short Tests For Exhaust Emission

(A) No Load Tests

(i) Idle/Fast Idle Tests (For Gasoline Vehicles)

- Pollutant (CO, HC, etc.) concentrations are measured at Idle Speed and 2000-3000 rpm
- 1 to 10 min. Duration
- Widely Used (Fastest, Cheapest, Easiest)
- Suitable for carbureted cars (detect malfunctioning of mixture preparation)
- Not very suitable for modern cars
- Not suitable for NOx

(A) No Load Tests (Cont..)

(ii) Idle/Fast Idle Tests with Lambda (λ) Test

- Similar to previous test
- Could identify malfunctioning modern mixture preparation systems
- Could be used to check the conversion efficiency of the catalyst

(A) No Load Tests (Cont..)

(iii) Free (or Snap) Acceleration Test (Diesel Vehicles)

- Engine is accelerated with the transmission in neutral position until its maximum speed and is then decelerated to its idle speed.
- Engine is loaded with its own inertia
- Amount of soot emissions is measured
- Very fast, cheap and easy to perform
- Procedure takes less than one minute
- Not suitable for NOx

(B) Steady-State Loaded Tests

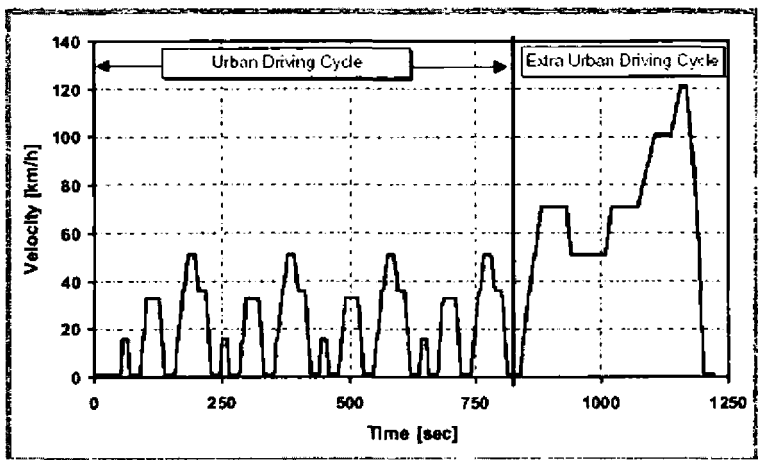
- Vehicle engine is driven at constant speed and load
- Involve a dynamometer with steady-state power absorption.
- Pollutant Concentrations / Smoke Levels are measured
- About 10 min. test duration
- Suitable for NOx measurements
- High equipment costs

(C) Transient Loaded Tests

- Vehicles are driven according to a specific driving schedule (or Cycle)
- Involve a dynamometer with transient power absorption.
- Exhaust gas samples are collected continuously over the test duration
- Emission is expressed in mass unit (g/km)
- Test duration widely varies (10 min to 1 hr)
- Best method to identify high emitters
- Very High equipment costs

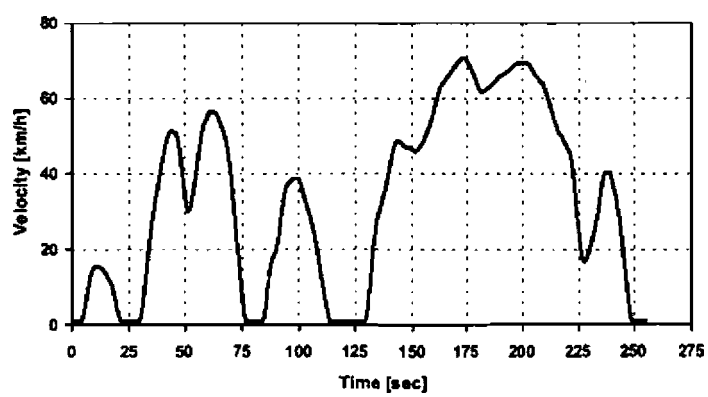
(C) Transient Loaded Tests (Cont..)

- **New European Driving Cycle**



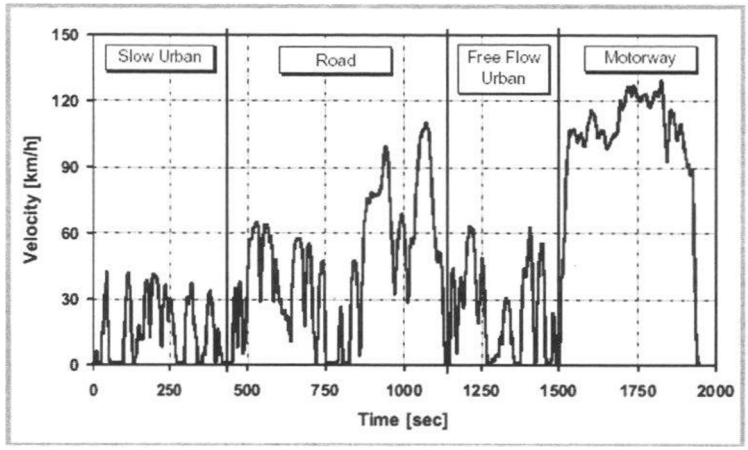
(C) Transient Loaded Tests (Cont..)

- **The Modern Short Driving Cycle**

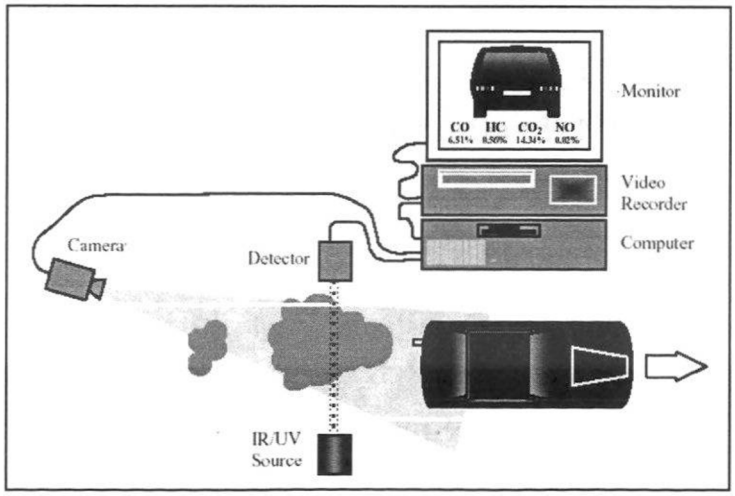


(C) Transient Loaded Tests (Cont..)

- **The Modern "Actual" Driving Cycle**



(D) Remote Sensing



(D) Remote Sensing (Cont..)

- An optical remote sensor is set up to transmit a beam of radiation
- Absorption of the transmitted radiation is used to determine the concentration of a gas
- Measure of emissions from a very large number of vehicles
- Measurement without any inconvenience to the vehicle driver
- Fully automated system with little man-power effort
- Variation in a vehicle's exhaust emissions with driving parameters.

4. TESTING EQUIPMENTS

4.1 Pollutants Covered

- CO, HC for Gasoline Vehicles
- PM (Soot) for Diesel Vehicles
- CO, HC and PM for 2-Stroke Vehicles

4.2 Tests Procedures:

- No Load Idle / Fast Idle Tests for Gasoline Vehicles
- No Load Snap Acceleration Test for Diesel Vehicles

4.3 Testing Equipments

(A) Idle/Fast Idle Tests (For Gasoline Vehicles)

- Horiba Exhaust Gas Analyzer (4-Gas)
- CO, HC, CO_2, O_2 (and λ) concentration Measurements



4.3 Testing Equipments (Cont..)

(B) Snap Acceleration Test (For Diesel Vehicles and Two-Stroke Gasoline Vehicles)

- Wager Partial Flow Smoke Meter
- Measure light absorption (opacity)
- Light absorbtion follows the Beer-Lambert Law: Opacity (%) = $100\ (1 - e^{(-K\,L)})$

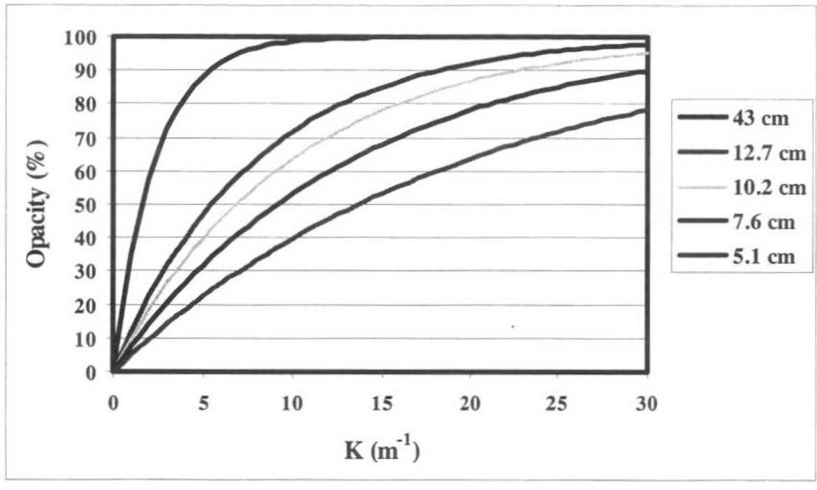
  K = index of absorbtion (density) of smoke (m^{-1})

  L = Path length of light through the smoke (m)

- New Sri Lankan regulations K = 8 m^{-1}

4.3 Testing Equipments (Cont..)

Opacity vs K – Factor at different Path Lengths L



4.3 Testing Equipments (Cont..)

Wager Smoke Meter

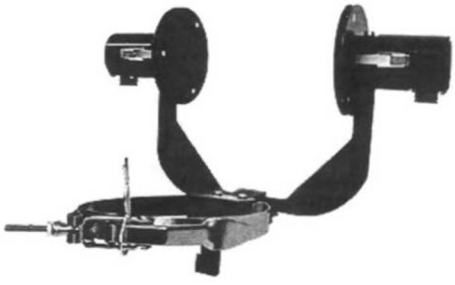


4.3 Testing Equipments (Cont..)

Wager Partial Flow Head



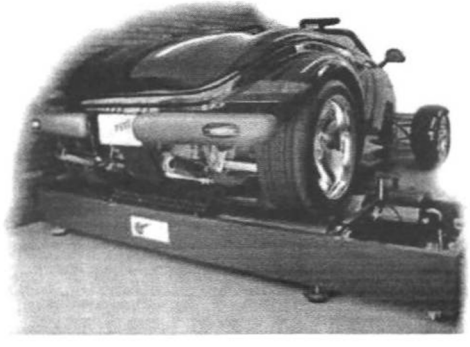
Wager Full Flow Head



4.3 Testing Equipments (Cont..)

(C) Load Tests

- **Chassis Dynamometer**

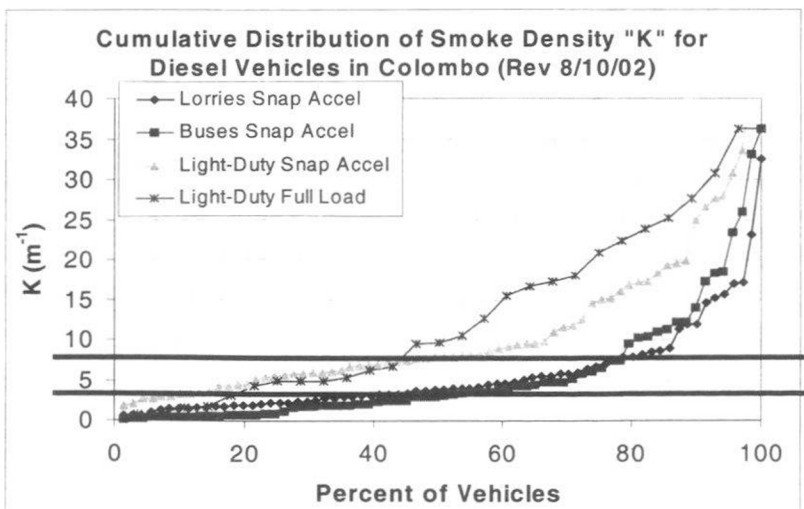




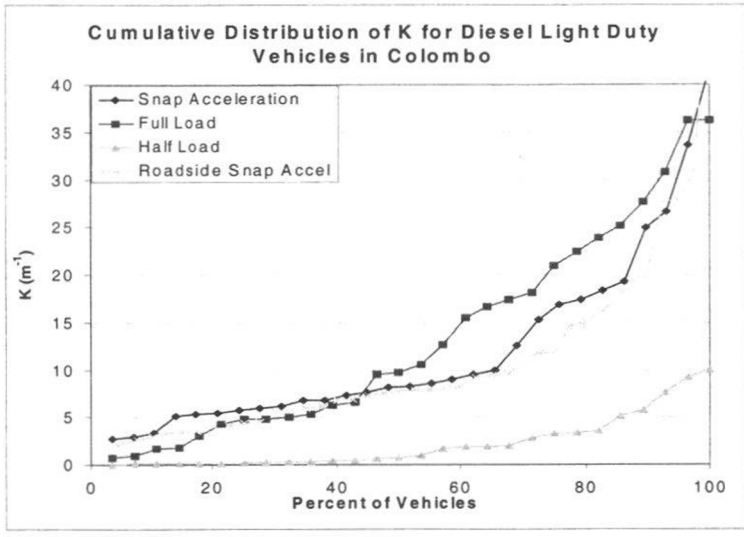
5. EMISSION MEASUEMENTS IN COLOMBO



5.1 Diesel Smoke Levels – Snap Acceleration Test



5.2 Diesel Smoke Levels of Light Duty Vehicles – No Load / Load Tests



Appendix D

Standard Operating Procedures of Emission Testing Equipments

APPENDIX D - 1

Standard Operating Procedure of the Gas Analyzer and Record Keeping Procedure of the Test Results

STANDARD OPERATING PROCEDURE	**SOP 001**
Title: **- Measuring Gaseous Emissions Using Horiba MEXA 554J 4-Gas Analyzer -**	**Page Number:**
Originator: Vehicle Emission Inspection Committee, Colombo, Sri Lanka	**Supersedes:** None
Responsible Organization: Department of Motor Vehicles & AirMAC	**Computer Program:** None
Type of Test Report: Forms	**Data Form Number:** Form SOP-01
Report Distribution: RMV & AirMAC, Traffic Department	**Implementation Date:** January 2003

Implementation Approval

Revision Description

1. Purpose

1.1 The purpose of this SOP is to measure the gaseous emissions using the Horiba MEXA-554J 4-gas analyzer from two- and three-wheelers.

2. Overview

2.1 The Horiba MEXA-554J 4-gas analyzer is used to measure the gaseous (CO, HC, CO_2 and O_2) emissions from two- and three-wheelers. This SOP provides step-by-step procedures for warming-up and calibrating the analyzer, for performing HC hang-up and leak checks, and for making emission measurement.

3. Applicability

3.1 Two-Wheelers Emission Measurement using Horiba MEXA-554J Gas Analyzer

4. References

4.1 Horiba MEXA-554J Gas Analyzer Manual

5. Required Equipment and Supplies

5.1 Horiba MEXA-554J Gas Analyzer, and sampling line and probe
5.2 Filters & calibration gas for Horiba MEXA-554J
5.3 Extension hoses
5.4 Gloves

6. Safety Precautions

6.1 Always wear gloves while handling the sampling probe and line, and used filters
6.2 Always exercise cautious in handling the calibration gas bottles

7. Quality Provisions

7.1 Instrument is properly warmed-up, calibrated, and HC hang-up and leak checked
7.2 Data are properly recorded
7.3 Sampling probe is properly inserted into the tailpipe

8. Inspection and Preparation

8.1 Connect the sampling line to the analyzer; check that the O-ring is fit into the slit on the measured gas inlet

8.2 Check that clean filter elements are fit to the prefilter unit, dust filter unit and strainer, and the elements are not dirty; replace filters if they are dirty or the filter clog sign appears ("F") on the screen
8.3 Check that the power-switch is off before connecting the power cable

Note:	Specific brand names described in these procedures are for reference only, and are not an endorsement of those products.

8.4 Turn on the power switch; the MEXA-554J analyzer will be automatically warmed-up for 5 minutes; the analyzer will be automatically performed zero calibration right after the warm-up
8.5 Calibrate the analyzer every week (e.g. every Monday morning); refer to Page 16 of the manual for span gas calibration
8.6 Perform HC Hang-Up Test; refer to Page 14 of the manual for HC Hang-Up Test
8.7 Perform Leak Check; refer to Page 15 of the manual for Leak Check
8.8 After passing the HC Hang-Up Test and Leak Check, the instrument is ready for emission measurement

9. Test Procedure

9.1 Start the engine of the vehicle, and leave it on idling
9.2 Press the "M" key which is located on the front panel; the "MEAS" mark will blink for 10 seconds and then the MEXA-554J will enter the measurement mode.
9.3 Insert the sampling probe into the exhaust pipe, and then retain the probe with a hook
9.4 For three-wheelers, attach the extension hose to the tailpipe then insert the sampling probe into the extension hose, and then retain the probe with a hook
9.5 After the values have stabilized, record the displayed values three times with a 30 second interval on the form SOP 001
9.6 Press the "M" Key after finish the measurement
9.7 Repeat Steps 9.1 to 9.6 for a new measurement
9.8 At the end of a test day, press the "M" key to suck clean air for about 30 minutes so that the sample line is purged
9.9 Turn off the power, disassemble the sampling line, and store the analyzer
9.10 Submit data forms for data analysis and filling

10. Data Recording

10.1 Record data on Form SOP001

11. Data Analysis

11.1 Submit Form SOP 001 to Supervisor for data analysis and filling

12. Data Reporting and Archival

12.1 Form SOP 001

13. Acceptance Criteria

13.1 Form SOP 001 was completed and QA/QC procedures were performed

14. Attachments

14.1 Attachment A: Forms SOP 001

Note:	Specific brand names described in these procedures are for reference only, and are not an endorsement of those products.

FORM SOP 001

Vehicle License Number:				
Vehicle Make & Model:				
Other Information:				
	HC (ppm)	CO (%)	CO2 (%)	O2 (%)
Idling				
1				
2				
3				
3,500 rpm				
1				
2				
3				

Note: Specific brand names described in these procedures are for reference only, and are not an endorsement of those products.

APPENDIX D - 2

Standard Operating Procedure of the Smoke Meter and Record Keeping Procedure of the Test Results

STANDARD OPERATING PROCEDURE	**SOP 002**
Title: **- Measuring Smoke Emissions Using Wager Smoke Meter -**	**Page Number:**
Originator: Vehicle Emission Inspection Committee, Colombo, Sri Lanka	**Supersedes:** None
Responsible Organization: Department of Motor Vehicles & AirMAC	**Computer Program:** None
Type of Test Report: Forms	**Data Form Number:** Form SOP-02
Report Distribution: RMV & AirMAC, Traffic Department	**Implementation Date:** January 2003

Implementation Approval

Revision Description

Note:	Specific brand names described in these procedures are for reference only, and are not an endorsement of those products.

1. Purpose

1.1 The purpose of this SOP is to measure the smoke emissions using the Wager 6500 Smoke Meter from diesel vehicles, and two- and three-wheelers.

2. Overview

2.1 The Wager Model 6500 smoke meter is used to measure the smoke opacity levels from diesel vehicles, and two and three-wheelers. This SOP provides step-by-step procedures for calibrate, and for making smoke measurement.

3. Applicability

3.1 Smoke Emission Measurement using Wager Smoke Meter

4. References

4.1 Wager Smoke Meter Manual

5. Required Equipment and Supplies

5.1 Wager Smoke Meter, sensor head and connecting cables
5.2 Extension hoses
5.3 Gloves

6. Safety Precautions

6.1 Always wear gloves while handling the sensor head and sampling line

7. Quality Provisions

7.1 Instrument is properly calibrated
7.2 Data are properly recorded
7.3 Sensor head is properly position in the tailpipe

8. Inspection and Preparation

8.1 Connect the sampling line to the smoke meter
8.2 Turn on the smoke meter; make sure that the sensor head of the unit is not obstructed (i.e. the path between the light source and detector is clear)
8.3 Select "Test Series" mode for T1, T2 and T3 measurement; If the unit is in "Follow" mode, press the "Zero" button to switch modes right after the unit is turned on
8.4 After selecting the mode, the unit automatically performs a self-calibration
8.5 Select the default stack size (5 in), and press save
8.6 Select the horsepower to "Unknown" and press save
8.7 Place the calibration glass to check for calibration. The result should show the value for the calibration glass
8.8 Block the light path with you hand. The result should read 100%. Remove your hand and check that the result is 0.0%. If it is not 0.0%, press the "ZERO" button to recalibrate the meter.

9. Test Procedure

9.1 Start the engine of the vehicle, and leave it on idling
9.2 Position the sensor head to the exhaust pipe
9.3 Press "Start Test" to begin test; the display will indicate "T1=" for the first test to be performed
9.4 Diesel Vehicles
- 9.4.a With the engine in neutral gear, rapidly accelerate the engine for one to four seconds. Return to idle.
- 9.4.b The display will show current opacity reading and the peak value reached during the test. Press "SAVE"
- 9.4.c The unit will display "T2 =" for the second test to be performed. Press "START TEST".
- 9.4.d Repeat 9.4.a to 9.4.b. Perform the same procedure for "T3="
- 9.4.e After the three tests are completed, press the "COMPUTE AVERAGE" button
- 9.4.f The "spread" is computed and displayed. If it is 5% or less, the test is valid. If it is above 5%, repeat the test until the spread meets the criteria

9.5 Two-Wheelers And Three Wheelers
- 9.5.a With the engine in idle, press "START TEST" for T1 measurement, and press "SAVE"
- 9.5.b After 10 seconds later, press "START TEST" for T2 measurement, and press "SAVE"
- 9.5.c After 10 seconds later, press "START TEST" for T3 measurement, and press "SAVE"
- 9.5.d After the three tests are completed, press the "COMPUTE AVERAGE" button
- 9.5.e The "spread" is computed and displayed. If it is 5% or less, the test is valid. If it is above 5%, repeat the test until the spread meets the criteria
- 9.5.f Repeat 9.5a to 9.5.e, for engine running at 3,500 rpm

9.6 Record the readings on FORM SOP-002 or print the readings
9.7 Repeat Steps 9.1 to 9.6 for a new measurement
9.8 At the end of a test day, turn the unit off, disassemble the sampling line, and store the smoke meter
9.9 Submit data forms for data analysis and filling

10. Data Recording

10.1 Record data on Form SOP002

11. Data Analysis

11.1 Submit Form SOP 002 to Supervisor for data analysis and filling

12. Data Reporting and Archival

12.1 Form SOP 002

13. Acceptance Criteria

13.1 Form SOP 002 was completed and procedures were properly followed
13.2 5% Spread criteria was met

14. Attachments

14.1 Attachment A: Forms SOP 002

FORM SOP 002

Diesel Vehicles

Vehicle License Number:	
Vehicle Make & Model:	
Other Information:	
	Smoke Opacity(%)
Snap Acceleration	
1	
2	
3	
Average	

Two-Wheelers or Three-Wheelers

Vehicle License Number:	
Vehicle Make & Model:	
Other Information:	
	Smoke Opacity(%)
Idling	
1	
2	
3	
Average	
3,500 rpm	
1	
2	
3	
Average	



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