ESM253

Bangladesh: Reducing Emissions from Baby-Taxis in Dhaka

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Abbreviations and Acronyms

API	American Petroleum Institute
ARAI	Automotive Research Association of India
BPC	Bangladesh Petroleum Corporation
BRTA	Bangladesh Road Transport Authority
BRTC	Bangladesh Road Transport Corporation
BSTI	Bangladesh Standards and Testing Institution
CB	contact breaker
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
DMP	Dhaka Metropolitan Police
DOE	Department of Environment
ESMAP	(Joint UNDP/World Bank) Energy Sector Management Assistance Programme
FC	fuel consumption
HC	hydrocarbons
HRF	high rainfall
ISO	International Organization for Standardization
JASO	Japanese Automobile Standards Organization
JFC	JASO FC
LED	light emitting diode
LRF	low rainfall
MECA	Manufacturers of Emission Controls Association
MEMR	Ministry of Energy and Mineral Resources
MoEF	Ministry of Environment and Forest
MRF	medium rainfall
NGO	non-governmental organization
NO_x	oxides of nitrogen
OS	original sequence
PM	particulate matter
PM_{10}	particles with an aerodynamic diameter less than 10 microns
$PM_{2.5}$	particles with an aerodynamic diameter less than 2.5 microns
PTT	Petroleum Authority of Thailand
PUC	pollution under control
RON	research octane number
RS	revised sequence
SAE	Society of Automotive Engineers
SIAM	Society of Indian Automobile Manufacturers
SMO	straight mineral oil
SUEP	Society for Urban Environmental Protection
Tk	Bangladeshi taka

UNDP	United Nations Development Programme
USAID	United States Agency for International Development
US$	United States dollars
US EPA	United States Environmental Protection Agency
VN	vehicle number

Units of Measure

cm	centimeters
g/km	grams per kilometer
kg	kilograms
km	kilometers
km/l	kilometers per liter
ml	milliliters
mm	millimeters
mm Hg	millimeters of mercury
m^3/min	cubic meters per minute
ppm	parts per million
$\mu g/m^3$	micrograms per cubic meter

Glossary of Terms

API TC A standard for two-stroke engine lubricant set by the American Petroleum Institute, considered the lowest acceptable level of 2T oil quality.

Carbon (deposit) Solid black residue in piston grooves that can interfere with piston ring movement leading to wear and/or loss of power.

JASO FB A standard for two-stroke engine lubricant set by the Japanese Automobile Standard Organization, approximately equivalent to API TC and ISO GB.

Mineral oil Petroleum based oil, traditionally forming the base for lubricants. To prevent deposit build-up, treatment with detergency/dispersancy additives is considered necessary.

Octane number A measurement of resistance to self-ignition (knocking) of a gasoline when mixed with air in an engine cylinder. The higher the octane number, the higher the anti-knock quality of the gasoline.

Opacity The amount of light blocked by smoke.

RON The anti-knock property of a fuel when vehicles are operated at low speed or under city driving conditions.

Scavenging loss Loss of unburned gasoline and lubricant as a result of by-passing the combustion chamber in a two-stroke engine vehicle during the fuel intake/gas exhaust phase of the engine cycle.

Snap acceleration smoke test A test (widely used for diesel vehicles) in which the vehicle is accelerated to predetermined speeds a number of times while the smoke density is measured using the light obscuration principle.

Straight mineral oil A mineral oil containing no additives. It is manufactured for use in slow-moving stationary engines, but not in vehicles.

Synthetic (and semi-synthetic) lubricant A lubricant containing a synthetic carrier such as polyisobutene and esters. If semi-synthetic, the formulation is based on a combination of mineral oil and a synthetic carrier, typically polyisobutene.

Two speed idle test A test in which carbon monoxide and hydrocarbons are measured at two pre-determined idle speeds.

Two-stroke The firing cycle of an engine where every piston stroke, which enlarges the combustion chamber volume, is a power stroke. The following stroke serves to exhaust the burned gases as well as induct and compress a fresh charge.

2T oil A lubricant especially formulated for use in two-stroke engine vehicles.

Executive Summary

1 The population of Dhaka, the capital of Bangladesh, grew at an annual rate of 6.4 percent, from 7.3 million to 11.4 million between 1992 and 1999. During the same period, the vehicle population grew even faster, at an estimated 8.9 percent per year. Air quality in Dhaka has continued to deteriorate in recent years. Because there are no major industries that may otherwise act as significant sources of emissions, much of the air pollution in Dhaka can reasonably be ascribed to the transport sector.

2 The most serious pollutant of concern in Dhaka is respirable and fine particulate matter. These particles enter the respiratory tract, reaching deep into the lungs, and have been demonstrated in a large number of studies to be linked to respiratory and other illnesses and to premature deaths. The ambient concentrations of respirable and fine particulate matter in Dhaka are two to three times higher than the air quality standards set in the United States and other countries.

3 Two important sources of fine particulate matter in Dhaka are diesel-powered vehicles and two-stroke engine gasoline vehicles. Among the latter, commercially operated three-wheel taxis (the so-called "baby-taxis") are estimated to account for more than one-third of the total number of kilometers traveled by all vehicles. Particulate emissions from baby-taxis are high partly because of incorrect use of lubricant. Specifically, drivers tend to use excess lubricant of the wrong type, called straight mineral oil. Because of their significant contribution to particulate emissions, this program has focused on emission reduction measures targeting baby-taxis.

Program Description

4 The program, "Reducing Emissions from Baby-Taxis in Dhaka," included the education of commercial two-stroke engine three-wheel vehicle drivers and owners through mechanics training, a baby-taxi "auto clinic," meetings, dissemination of information, and informational meetings with auto mechanics and gasoline station owners who come in contact with vehicle drivers on a regular basis. The activity also sought to restructure the market for lubricants through both private voluntary action and government policy reform. To this end, the following activities were undertaken:

- Quantifying the impact of the use of excess inferior quality lubricant on emissions from baby-taxis
- Training of mechanics servicing baby-taxis
- Holding an auto clinic to demonstrate to the drivers the merit of changing their behavioral pattern with respect to the use of lube oil and vehicle maintenance
- Consensus-building within the downstream petroleum sector on a ban on the sale of straight mineral oil at gasoline stations
- Other awareness-raising and dissemination activities to educate the drivers and the public on what affects vehicle emissions.

Mass Emission Measurements

5 Three baby-taxis ranging in age from four to seven years were selected, inspected for their mechanical condition, and tested for mass emissions of particulate matter, hydrocarbons, carbon monoxide (CO), and oxides of nitrogen (NO_x). The parameters that were examined in the test matrix included the type of lubricant (straight mineral oil which is not designed for use in vehicles, mineral-oil-based 2T oil especially formulated for use in two-stroke engine vehicles, and higher quality low smoke 2T lubricant containing a synthetic carrier); quality of gasoline; and the amount of lubricant.

6 The results showed that particulate emissions were most strongly dependent on the mechanical state of the vehicle, and that vehicle servicing decreased particulate emissions. The particulate emissions also decreased when the lubricant was switched from straight mineral oil to mineral-oil-based 2T oil; however, using low smoke lubricant (for which smoke emissions are known to decrease) had no further impact on particulate emissions. Decreasing the concentration of lubricant from 8 percent, commonly used by many baby-taxis, to 3 percent—corresponding to the vehicle manufacturers' recommendation—also decreased emissions significantly. The type of gasoline used had much less impact on emissions.

7 The type of lubricant used had no impact on other pollutants, specifically CO, hydrocarbons, and NO_x. In the case of CO, using 8 percent lubricant decreased emissions. Although a statistical design was used to carry out the experimental program, the number of tests conducted was limited and hence the results should be interpreted with caution.

8 Smoke opacity measurements were not well correlated with mass particulate emissions below 1 gram per kilometer (g/km). Above 1 g/km, depending on the test mode, there was a reasonable correlation between mass particulate emissions and opacity measurements. An oxidation catalyst appears to have decreased particulate emissions when the latter were high (for example, using 8 percent straight mineral oil).

Mechanics Training and Auto Clinic

9 Auto mechanics service baby-taxis and advise drivers on vehicle maintenance as well as the use of lubricant. Therefore, providing accurate information to auto mechanics in the area of emissions mitigation is a vital component of air quality management in Dhaka. About 400 mechanics for baby-taxis were trained in proper servicing and repair, and the impact of incorrect servicing and poor maintenance on emissions.

10 The training included health aspects of vehicle emissions and causes for high smoke emissions. Visual demonstrations of smoke emissions from baby-taxis using the correct gasoline/lubricant formulation and those using the wrong quantity and quality of lubricant were given in each session.

11 The principal focus of this ESMAP program was an auto clinic offering free vehicle inspection, minor servicing, emissions measurements, and medical examination. The auto clinic was held between October 10 and November 9, 2000. One thousand baby-taxi drivers participated in the auto clinic. A survey was conducted with each driver, who was also examined by a doctor and given medication if found ill. Each vehicle was examined and tested for emissions. Those found to be failing were serviced and tested again for emissions, up to

two times. The drivers were given pamphlets on the correct use of lubricant and proper maintenance.

12 Of the thousand drivers, only five were found to be using 2T oil. The average quantity of lubricant added to gasoline was 8 percent, nearly three times the amount recommended by the vehicle manufacturer. The majority of vehicles inspected showed signs of ad hoc repair. Many were leaking. Because leaking exhaust systems can cause dilution of the exhaust gas sample, accurate measurements of emissions were difficult, and in fact a large number of vehicles registered low levels of pollutant emissions.

13 Many drivers reported that they were sick, on average seven days a month. This affected their income—they worked until they were too sick to drive. There was a unanimous agreement that baby-taxis contributed to air pollution in Dhaka and that more should be done to reduce emissions from baby-taxis.

14 The emissions data collected clearly showed that smoke emissions decreased with decreasing lubricant concentration and as a result of using 2T rather than straight mineral oil. The following lessons may be summarized from the analysis of emissions data collected.

- Statistical analysis is a powerful tool for assessing the impact of various parameters on emissions. Such analysis in turn is essential if the World Bank's policy recommendations are to be based on sound science. Statistical analysis can help test widely held perceptions, and having data and analysis to support or refute these perceptions is important, especially if stringent regulations (such as banning vehicles older than a certain age, or mandating expensive but low-smoke-producing semi-synthetic lubricant) are being envisaged.
- The statistical framework for the analysis to be undertaken must be set up prior to conducting the auto clinic, so that the necessary data are collected. All too often, there is a tendency to start thinking rigorously about data reduction only after all the data have been collected, by which time it is too late if one or more pieces of crucial data are missing.
- Measurement errors arise from a number of sources and affect statistical analysis. In the Dhaka auto clinic, three main sources of measurement errors seemed to have played an important role: (1) handling of the CO/hydrocarbon meter, (2) poor reproducibility in measuring smoke at high idle (multiple readings of CO and hydrocarbons were not taken for each vehicle), and (3) leakage, potentially causing dilution of the exhaust gas sample. If the last problem were common, it would be very difficult to identify gross emitters, and in fact such a problem would defeat the purpose of an inspection and maintenance program, however well-run.
- Drivers and mechanics are adept at circumventing the purpose of the emissions testing procedure. Toward the end of the clinic many, if not most, drivers learned from others that in order to "pass," they would need to reduce the amount of lubricant added. Some even arrived with the vehicle having no lubricant added to the gasoline, an otherwise undrivable condition in the long run.

- The data collected supported the hypothesis of declining smoke emissions with decreasing lubricant quantity and using 2T oil rather than straight mineral oil. The impact of vehicle age on emissions was much less clear and would need to be investigated further.
- There were also factors other than those identified (such as the conditions of the air filter, carburetor, and spark plug, and the time elapsed since last service) that had a considerable impact on emissions. Since these unidentified factors accounted for more than 90 percent of the total emissions, more work to identify what these factors might be would be useful.

Consensus-Building and Regulatory Change

15 Immediately following the first auto clinic, a seminar on lubricant and gasoline quality was held on November 21, 2000, attended by more than 100 participants from the energy, environment, and transport sectors, including government representatives, oil marketing companies, vehicle marketers, vehicle drivers, vehicle owners, and the traffic police. The seminar discussed how best to promote the correct use of lubricant in two-stroke engine vehicles and made recommendations. The recommendations included a ban on the sale of straight mineral oil for use in vehicles and making API TC or JASO FB (technical specifications for lubricant quality) as minimally acceptable 2T oil quality throughout Bangladesh by March 2001.

16 Responding to the growing recognition of the importance of using 2T oil and the consensus that the use of straight mineral oil in vehicles should not be allowed, the Bangladesh Petroleum Corporation issued in January 2001 a notification prohibiting the sale of straight mineral oil for use in two-stroke engine vehicles, and setting API TC or JASO FB as minimally acceptable standards for 2T oil.

17 The decision of the Government of Bangladesh to ban the sale of straight mineral oil and set standards for 2T oil is a significant step. In order to ensure that this move has measurable effects on the ground, these regulations need to be implemented and enforced. The first condition is that 2T oil meeting the minimal standards be made widely available. The cooperation of oil marketers and retail outlet owners and attendants is crucial for this purpose.

18 In October 2001, one lubricant marketer launched the sale of 2T oil in 60 milliliter (ml) sachets. The sale of 2T oil in sachets was one of the important recommendations of the November 2000 seminar. Such a move would minimize the chances of excess use of lubricant in baby-taxis. The public education campaign is continued in the World Bank's Learning and Innovation Loan, Bangladesh Air Quality Management Project. In particular, a second baby-taxi auto clinic was held in December 2001-January 2002 under the auspices of this project to assess the impact of the ban on the sale of straight mineral oil and the sale of 2T oil in 60 ml sachets on the actual lubricant use and emission levels, and to raise the awareness of various stakeholders as well as the general public regarding the role of lubricant in reducing emissions.

1

Air Pollution in Dhaka

1.1 The population of Dhaka, the capital of Bangladesh, grew at an annual rate of 6.4 percent, from 7.3 million to 11.4 million between 1992 and 1999. During the same period, the vehicle population grew even faster, at an estimated 8.9 percent per year. Air quality in Dhaka has continued to deteriorate in recent years. Because there are no major industries that may otherwise act as significant sources of emissions, or a desert nearby as a source of dust storms, much of the air pollution in Dhaka can reasonably be ascribed to the transport sector.

Respirable Particulate Matter

1.2 The most serious pollutant of concern in Dhaka is respirable and fine particulate matter, PM_{10} (particles with an aerodynamic diameter less than 10 microns) and $PM_{2.5}$ (particles with an aerodynamic diameter less than 2.5 microns). PM_{10} and $PM_{2.5}$ remain in suspension in the air for hours or days and can travel large distances from their source. These particles enter the respiratory tract, reaching deep into the lungs. PM_{10} includes all particles likely to pass through the nose and mouth. $PM_{2.5}$ includes particles able to reach the deeper parts of the respiratory tract, especially the alveolar regions of the lung. These small particles have in turn been demonstrated in a large number of studies to be linked to respiratory and other illnesses and premature deaths. The data taken at an urban and a rural site in Dhaka in the 1990s are shown in micrograms per cubic meter ($\mu g/m^3$) in Table 1.1.

Table 1.1: Ambient PM_{10} and $PM_{2.5}$ Concentrations ($\mu g/m^3$) in Dhaka

Size fraction	*Urban*	*Rural*	*USEPA*[1]
PM_{10}	123±82	56±35	50
$PM_{2.5}$	51±43	21±11	15
$PM_{2.5–10}$[2]	72±69	35±33	—

Notes: Data taken in 1993 and 1994 at the urban site and between 1995 and 1996 at the rural site. Urban: located 50 meters away from a road in a semi-residential area in Dhaka. Rural: located 500 meters away from a local road and 6 kilometers away from a highway in Savar, 40 kilometers north of Dhaka.
— not applicable.
[1] Air quality standards for PM_{10} and $PM_{2.5}$ set by the United States Environmental Protection Agency (USEPA), annual averaged.
[2] Particles with an aerodynamic diameter between 2.5 and 10 microns, also called “coarse” particles.
Source: Biswas 1998.

1.3 As suggested by the large standard deviations, there is considerable scatter in the data, reflecting in part variations associated with seasonal rainfall. The particulate matter concentrations are the highest from November to January, corresponding to the low rainfall season, with an average rainfall of less than 2 centimeters (cm) per month, and they are the lowest from June to August, corresponding to the high rainfall season, with an average rainfall of greater than 30 cm per month. These trends are shown in Table 1.2. At the urban site, the average PM_{10} concentration was found to increase seven-fold between the high rainfall and low rainfall seasons, while the $PM_{2.5}$ concentrations increased five-fold. The variations at the rural site were not as great, giving four-fold and three-fold increases between the low and high rainfall seasons for PM_{10} and $PM_{2.5}$, respectively. Data have also been collected at hot spots and they show that particulate concentrations are many times higher at busy road junctions.

Table 1.2: Impact of Rainfall on PM_{10} and $PM_{2.5}$ Concentrations (μg/m³) in Dhaka

	Urban			Rural		
Size fraction	*LRF*	*MRF*	*HRF*	*LRF*	*MRF*	*HRF*
PM_{10}	230±110	76±44	30±10	98±33	66±47	23±9
$PM_{2.5}$	88±47	34±16	17±5	35±10	24±10	12±4
$PM_{2.5–10}$	140±67	42±28	13±7	63±23	42±37	11±5

For explanations of urban and rural, see Notes, Table 1.1. LRF low rainfall, MRF medium rainfall, HRF high rainfall.
Source: Biswas 1998.

1.4 To assess the impact of high PM_{10} concentrations on health, 90 percent of the population was assumed to be exposed to concentrations corresponding to the average value at the urban site in Table 1.1, and the remaining 10 percent to concentrations three times higher than the average shown in Table 1.1. Elevated PM_{10} concentrations were found to be responsible for an estimated 6,000 premature deaths and 50,000 cases of chronic bronchitis.

Vehicular Emissions in Dhaka

1.5 Vehicles emit a number of harmful pollutants, including small particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), and oxides of sulfur. Vehicular emissions of fine particles are especially harmful because they occur near ground level, close to where people live and work. A chemical mass balance and modeling study carried out using the data shown in Table 1.2 indicated that during the low rainfall season, two-fifths of $PM_{2.5}$ and one-fifth of PM_{10} were due to vehicular exhaust (Biswas 1998).

1.6 Three-hundred thousand vehicles are registered in Dhaka, of which there are about 65,000 three-wheel taxis, commonly referred to as “baby-taxis,” used for short-distance travel. The majority of the baby-taxis are based on a two-stroke engine design and imported from India. There are 120,000 two-wheelers, the majority of which are also powered by two-stroke engines. Two-wheelers include mopeds, scooters, and motorcycles, and are used mostly for personal transportation. However, in terms of the distance covered, the baby-taxis—being commercial vehicles and thus being driven much more than most two-wheelers—are estimated to account for more than one-third of the total number of kilometers traveled by all vehicles, whereas two-wheelers account for only one-tenth of the total kilometers.

1.7 Two-stroke engines have several advantages over four-stroke engines. These include lower cost; excellent torque and power; mechanical simplicity (fewer moving parts and resulting ease of maintenance); lighter and smaller engines; greater operating smoothness; and lower nitrogen oxide emissions. They also have disadvantages compared with four-stroke gasoline engine vehicles, including higher particulate and hydrocarbon emissions, lower fuel economy, and louder noise.

1.8 Hydrocarbon and smoke emissions are higher with two-stroke engines because of the design of the engine. Gas is exchanged through ports located in the cylinder, usually opposite each other. A fresh fuel and air mixture compressed in the crankcase enters through the intake opening, while exhaust gases exit through the exhaust port. While both the intake and exhaust ports are open, some of the fresh fuel and air mixture escapes through the exhaust port. As a result of these "scavenging losses," which can amount to 15–40 percent of the unburned fresh charge, the exhaust contains a high level of unburned fuel and lubricant (MECA 1999). Nitrogen oxide emissions tend to be lower because a significant portion of the combustion products remains in the cylinder.

1.9 Two important sources of PM_{10} in Dhaka are diesel-powered vehicles and two-stroke engine gasoline vehicles. The nature of the particles differs between these two types of vehicles. In the case of diesel vehicles, particulate emissions consist largely of graphitic carbon, whereas in the case of two-stroke engine gasoline vehicles, particulate emissions are dominated by fine oil droplets from the lubricant added directly to gasoline. These oil droplets in turn are responsible for the visible smoke, the emissions of which are exacerbated by the use of the wrong quality and quantity of lubricant.

Gasoline and Lubricant Quality

1.10 There are two grades of gasoline in Bangladesh, corresponding to research octane numbers (RON) of 80 and 95. The minimum octane number specified by three-wheeler vehicle manufacturers is 87 RON, while the minimum required for modern engine passenger cars is 91–92 RON. Depending on how the driver shifts the gear, the low octane level of gasoline can cause engine knocking, leading to engine damage and higher emissions.

1.11 Bangladesh Petroleum Corporation (BPC), the sole supplier of gasoline in the country, phased lead out of gasoline in July 1999, thereby eliminating one significant source of lead emissions. Lead is an octane enhancer and was traditionally added to gasoline throughout the world until about two to three decades ago. Lead has since been found to be extremely damaging to public health, especially to the intellectual development of children, even at levels previously considered safe. In the case of two-stroke engine vehicles, some of the lead emitted is in the form of organic lead, which is even more damaging than inorganic lead; the latter is formed by the combustion of lead additives used in gasoline. Because of its health impact, a number of countries have now banned the use of lead in gasoline, and Bangladesh became the first country in South Asia to do so in 1999.

1.12 The adulteration of gasoline with kerosene, because of the difference in their retail prices, is a problem in Bangladesh. This malpractice increases emissions because not only does kerosene lower the already low octane of the regular grade gasoline sold in Bangladesh, it also has a higher boiling point than gasoline and is therefore more difficult to burn. As a result, more deposits build up in the engine and damage the engine over time, and more unburned hydrocarbons are emitted in the exhaust gas.

1.13 Lubricant requirements for two-stroke engines differ from those for four-stroke engines and are characterized by good lubricity; piston cleanliness; low deposits, especially in the exhaust system; and low smoke emission. Two-stroke engine vehicles should use specially formulated 2T (two-stroke) oil. Vehicle manufacturers recommend adding 3 percent 2T oil to gasoline for three-wheelers.

1.14 In the mid-1980s the American Petroleum Institute (API) and the Coordinating European Council for the Development of Performance Tests for Transportation Fuels, Lubricants, and Other Fluids set up a provisional two-stroke lubricant performance and service classification list. API canceled the system in 1993, deferring to the International Organization for Standardization (ISO) global specification and the Japanese Automobile Standards Organization (JASO) system. Oil marketers continue to use the outdated test criteria established for API TC to certify air-cooled oils. The API TC classification is currently the lowest acceptable level of 2T oil quality.

1.15 In 1990 JASO created a two-stroke lubricant standard with three levels of quality (FA, FB, and FC). Lubricity and detergency quality increase from FA to FC, and exhaust blocking and smoke emission improve. The smoke density of these oils is determined in JASO tests on a Suzuki Generator SX 800R engine under specific steady-state operating conditions on a comparative basis with the smoke density of a standard “low smoke” reference oil. Maximum permissible levels of smoke density in JASO tests are 50 percent for FA oil, 44 percent for FB oil, and 24 percent for FC oil. Japanese manufacturers of two-stroke vehicles identify FC (low-smoke lubricants) as their minimum requirement. North America’s API TC oil rating is equivalent to JASO FB, although the API ratings do not include smoke as a parameter.

1.16 Since April 1999 the Government of India has required that all two-stroke engine oils sold in the country meet both API TC and JASO FC specifications (that is, only low-smoke lubricating oils can be used in India). In the National Capital Territory of Delhi, 2T oil can be sold only in sealed packages or premixed with gasoline and dispensed through the pump nozzle. This ban on unsealed packages is intended to discourage the sale of recycled and other unsuitable engine oils. The sale of premixed gasoline is intended to encourage the use of both a suitable quality and the correct amount of 2T oil.

1.17 The majority of baby-taxi drivers in Dhaka do not use 2T oil. Instead, they use straight mineral oil which is manufactured for use only in slow-moving stationary engines. One reason for this use is that straight mineral oil is the lubricant of choice sold at gasoline filling stations to baby-taxi drivers. The oil is typically automatically added to gasoline as the vehicle drives up to the station attendants. This practice is so entrenched that it is actually difficult for baby-taxi drivers to purchase gasoline without the addition of straight mineral oil.

For example, as recently as November 2000, the organizers of the baby-taxi auto clinic under this ESMAP program found it difficult either to refuel four-stroke engine three-wheelers (which do not require the addition of lubricant to gasoline) or purchase gasoline without the addition of straight mineral oil so that proper 2T oil could be added. Several filling stations refused to sell gasoline without the addition of straight mineral oil.

Lubricant Quantity

1.18 Another reason for high smoke emissions is the addition of excess lubricant to gasoline. Purchasing 6 liters of gasoline with 500 milliliters (ml) of straight mineral oil, or 3 liters of gasoline with 250 ml of oil, is common, corresponding to a lubricant content of 8 percent rather than the vehicle manufacturers' recommendation of 3 percent. Because lubricants have much higher molecular weight and boiling point than gasoline, they are more difficult to burn. The combined effect of incomplete combustion and the "scavenging" losses when the fuel contains more lubricant is higher particulate and smoke emissions.

1.19 Switching from 8 percent straight mineral oil to 3 percent 2T oil need not incur any additional expense to drivers. Straight mineral oil is typically sold for about Tk 50 per liter. A reduction of 62.5 percent means that drivers break even even if the price of 2T oil were as high as Tk 130/liter (which it is not). At the current retail price, drivers can actually save money by reducing the amount of lubricant they purchase and switching to proper 2T oil simultaneously. Vehicle components will also remain clean longer because reduced use of lubricant results in less deposition of carbonaceous materials. In short, using the correct quantity and quality of lubricant is a "win-win" measure that helps both drivers and the public at large, who will benefit from lower vehicular emissions.

Vehicle Maintenance

1.20 Another reason for high smoke emissions from baby-taxis is poor vehicle maintenance. Simple servicing procedures—cleaning and adjusting the carburetor, adjusting the ignition system, cleaning and adjusting or replacing spark plugs, and cleaning air filters—can reduce exhaust emission levels significantly as well as improve fuel efficiency. Vehicle manufacturers recommend that in the case of two-stroke engine baby-taxis, air filters should be cleaned or replaced every 3,000 kilometers (km); carburetors tuned and cleaned every 3,000 km; decarbonization carried out every 6,000 km for three-wheelers and 9,000 km for scooters; minor engine overhauls typically conducted every 30,000 km for two-stoke engines; and major overhauls every 90,000 km for two-stroke engine three-wheelers.

1.21 Proper maintenance is critical to reaping the full benefits of investments in emission mitigation. Lack of proper maintenance becomes even a greater problem when drivers lease their vehicles, because neither the driver nor the owner feels solely responsible for the mechanical condition of the vehicle.

Overall Program Description of "Reducing Emissions from Baby-Taxis in Dhaka"

1.22 The ESMAP activity, "Reducing Emissions from Baby-Taxis in Dhaka," focused on the education of commercial two-stroke engine vehicle drivers and owners through mechanics training, a baby-taxi "auto clinic," meetings, dissemination of information, and informational meetings with auto mechanics and gasoline station owners who come in contact with vehicle drivers on a regular basis. The activity also sought to restructure the market for lubricants through both private voluntary action and government policy reform. To this end, the following activities were undertaken:

- Quantifying the impact of the use of excess inferior quality lubricant on emissions from baby-taxis
- Training of mechanics servicing baby-taxis
- Holding an auto clinic to demonstrate to the drivers the merit of changing their behavioral pattern with respect to the use of lube oil and vehicle maintenance
- Consensus-building within the downstream petroleum sector on a ban on the sale of straight mineral oil at gasoline stations
- Other awareness-raising and dissemination activities to educate the drivers and the public on what affects vehicle emissions.

1.23 This report describes the above activities. Three baby-taxis ranging in age from four to seven years were selected, inspected for their mechanical condition, and tested for mass emissions of particulate matter, hydrocarbons, CO, and NO_x. The parameters that were examined in the test matrix included the type of lubricant (straight mineral oil, mineral-oil-based 2T oil, and low smoke lubricant); quality of gasoline; and the amount of lubricant. About 400 mechanics for baby-taxis were trained in proper servicing and repair, and the impact of incorrect servicing and poor maintenance on emissions.

1.24 The principal focus of this ESMAP program was an auto clinic offering free vehicle inspection, minor servicing, emissions measurements, and medical examination. The auto clinic was held between October 10 and November 9, 2000. One thousand baby-taxi drivers participated in the auto clinic. A survey was conducted with each driver, who was also examined by a doctor and given medication if found ill. Each vehicle was examined and tested for emissions. Those found to be failing the stipulated emissions were serviced and tested again for emissions, up to two times. The drivers were given pamphlets on the correct use of lubricant and proper maintenance.

1.25 Immediately following the auto clinic, a seminar on lubricant and gasoline quality was held on November 21, 2000, attended by more than 100 participants from the energy, environment, and transport sectors, including government representatives, oil marketing companies, vehicle marketers, vehicle drivers, vehicle owners, and the traffic police. The seminar discussed how best to promote the correct use of lubricant in two-stroke engine vehicles and made recommendations.

1.26 Responding to the growing recognition of the importance of using 2T oil and the consensus that the use of straight mineral oil in vehicles should not be allowed, in January 2001, the Bangladesh Petroleum Corporation issued a notification prohibiting the sale of straight mineral oil for use in two-stroke engine vehicles and setting minimally acceptable standards for 2T oil. Public education campaigns through auto clinics and surveys of lubricant use are continuing under the leadership of the Department of Environment.

2

Measuring Particulate Emissions

2.1 Nearly all the work carried out to date on two-stroke engine vehicles has focused on reducing hydrocarbons (or the sum of hydrocarbons and nitrogen oxides), CO, and visible smoke. No in-depth study has been conducted on mass emissions of particulate matter. There is no established methodology that has been accepted industry-wide for measuring particulate emissions from two-stroke engines. As a result, little quantitative information is available on the impact of varying lubricant quality and quantity on mass particulate emissions.

2.2 Measurement of particulate emissions from two-stroke engines is difficult because oil droplets from lubricant added to gasoline on a pass-through basis account for a large fraction of particulate matter in the exhaust gas. Depending on the dilution rate and the temperature to which the line downstream of the exhaust pipe (including the dilution tunnel) is heated, these droplets can condense before being collected on filter paper. Oil samples condensed on filter papers can also be lost as a result of the passage of gas through the filter.

2.3 Preliminary work carried out at AEA Technology in the United Kingdom showed that while the regulatory filter method may give mass particulate emissions that are about 60 percent lower than those that result in the method using the Andersen impactor (where the passage of gas through the filter is circumvented) (Kojima and others 2000), there was a linear relationship between the mass emissions measured using the regulatory method and the Andersen impactor method. Therefore, even if some systemic losses did occur, the use of the regulatory method would provide a satisfactory comparative method: the absolute values may not be exactly correct, but the correlation between vehicles and oils would be valid.

2.4 The regulatory filter method was employed at the research facilities of the Automotive Research Association of India (ARAI) in Pune in the summer of 2000 to measure mass emissions from three baby-taxis from Dhaka. Bajaj Auto Limited, India, and AEA Technology, United Kingdom, provided technical assistance for this program. Additionally, data on CO, hydrocarbons, NO_x, carbon dioxide (CO_2) and opacity were collected, and fuel economy was calculated from the data collected for each test.

2.5 A double roller chassis dynamometer with a diameter of 410 millimeters (mm) was used. The vehicle exhaust pipe was connected to the insulated inlet of a full flow Fisher Rosemount dilution tunnel with a diameter of 25.4 centimeters. The constant volume sampling venturi at 6 and 9 cubic meters per minute (m^3/min) was used to measure the total diluted exhaust volume. A standard regulatory filter sample for particulate matter was taken at 25 liters per minute onto 70 mm diameter Pallflex type TX40HI20-WW filters. Bags of exhaust gas were collected for analysis of CO, hydrocarbons, NO_x, and CO_2 on Fisher Rosemount analyzers. A Celesco Telonic/Berkeley model 300 portable opacity meter was used to measure percent opacity under free acceleration and at idle.

Selected Baby-Taxis

2.6 Three vehicles manufactured in 1993 (vehicle 3), 1995 (vehicle 1), and 1996 (vehicle 2) were selected and their engines were shipped from Dhaka to Pune, India. Bajaj redesigned their three-wheelers in order to meet the revised emission standards implemented in India in 1996. Therefore, these vehicles represent pre- and post-1996 vehicle technology, with vehicle 2 having been manufactured to meet the 1996 Indian emission standards. The engines of vehicles 1 and 3 had two transfer ports and one exhaust port, while that of vehicle 2 had three transfer ports and one exhaust port. Upon arrival, the engines were inspected and mounted on the chassis provide by Bajaj Auto, the original equipment manufacturer of the three baby-taxis. Considerable evidence of ad hoc and incorrect repairs was found during the inspection. The inspection findings that are likely to affect emission measurements are given in Table 2.1. Other observations included broken cylinder block and cylinder head fins, broken air filter mounting lugs, a crankcase that did not appear to be the original, an aluminum welding patch on the side of a crankcase gear box (suggesting that the crankcase might have broken or cracked on the gearbox side and the welding performed to prevent leakage and/or to arrest crack propagation), and light seizure marks on the piston.

Table 2.1: Observations and Corrective Actions Taken

Findings	*Vehicle number*	*Corrective action*	*Likely impact*
Fan cover missing	3	Provided cover	Engine is likely to overheat without the fan cover
Engine cowling missing	All	Provided cowling	Engine is likely to overheat without the cowling
Engine output shaft substantially modified from original serrations to two flat faces	1 and 3	Disassembled the engine and replaced the output shaft with a proper one	The output shaft could not be assembled to the differential. It was necessary to disassemble the engine almost completely to be able to replace the output shaft. Although extreme precaution was taken not to disturb the deposits in the engine, the engine would not be, strictly speaking, in the "as-received" condition

Methodology

2.7 AEA Technology prepared a test matrix using factorial design. The test matrix was based on a D-optimal design produced by the Design-Expert software package, which performs matrix manipulations to find the combination of tests that maximizes the amount of information and the degree of confidence in the results. The parameters investigated, shown in Table 2.2, were the vehicle age, the state of vehicle maintenance, quality of gasoline, quality of lubricant, quantity of lubricant, and the installation of an oxidation catalyst. It should be mentioned that the examination of the impact of installing an oxidation catalyst was not included in factorial design and hence does not appear in the test matrix. Servicing of vehicles 1 and 3 is described in Table 2.3.

Table 2.2: Parameters Tested

Parameter	*Description*
Gasoline quality	(1) 1998 Indian reference gasoline with 87 RON
	(2) Blend of gasoline from five gasoline stations in Dhaka, all 80 RON
Lubricant quality	(1) Straight mineral oil from Dhaka
	(2) Regular 2T oil purchased in India
	(3) JASO FC grade “low smoke” oil purchased in India
Lubricant quantity	3 and 8 percent
Vehicle age	4, 5, and 7 years
Maintenance	Before and after service on vehicles 1 and 3, and reconditioning of vehicle 2
Catalyst[a]	Retrofit vehicle 2 with an oxidation catalyst for the test numbers 34, 35, and 36

[a] Catalyst manufactured by Allied Signal, installed commercially in Bajaj vehicles meeting the year 2000 emission standards.

Table 2.3: Servicing of Vehicles 1 and 3

Parts	*Action taken*
Spark plug	Cleaned and the gap reset
Carburetor	Cleaned and readjusted
Air filter	Cleaned and air gap reset
Clutch/gear/accelerator play	Adjusted
Exhaust	Checked for leakage and corrected by welding silencer joints
Tire pressure	Set to recommended pressure
Oil levels, cylinder head block, cylinder head bolts, ignition timing, brake setting, compression, clutch/gear/accelerator play	Checked and found acceptable

2.8 Separate fuel lines and tanks were used for different fuel oil combinations. The vehicles (without the catalyst) were subjected to one hour of cooling by a fan. Vehicle 2 retrofitted with the catalyst was soaked for 6 to 30 hours at a temperature ranging from 20° to

30°C. The vehicles were first subjected to six Indian driving cycles on the chassis dynamometer as part of preconditioning. Samples of CO, hydrocarbons, NO_x, CO_2, and particulate matter were collected during the next six Indian driving cycles. Fuel consumption was calculated from carbon material balance. Fifteen tests were carried out before vehicles 1 and 3 were serviced. After six tests, vehicle 2 had a major breakdown and had to be repaired. The repair involved replacing the piston and piston rings, honing the cylinder block, and changing the crank shaft bearing and oil seal. As a result, the test sequence had to be altered from the original generated by the computer program. The repair carried out to vehicle 2 cannot be treated as "service" since the stipulated items of "service" as listed in Table 2.3 were not carried out on this engine. Only the seized piston and rings were replaced with utmost care while ensuring that the engine deposits and so on were not disturbed. This repair could be classified as "essential reconditioning." However, the obtained results showed that even this reconditioning lowered emissions. All the tests carried out on vehicle 2 before reconditioning were repeated after reconditioning.

Results

2.9 The original test sequence, the actual test sequence, various parameters, and the mass emission measurement results in grams per kilometer (g/km) are given in Table 2.4. Fuel economy was calculated from carbon material balance and is given in the table in kilometers per liter (km/l) of gasoline. Originally, the tests were divided into two blocks, with the first block of 15 testing all vehicles before any repair service, and the second block testing vehicles after vehicles 1 and 3 had been serviced. According to the original test matrix, vehicle 2 would remain unserviced throughout, and the test order within each block would be randomized to minimize the effect of atmospheric conditions. For all the other variables the effect of atmospheric conditions could be minimized as much as possible by randomizing the run order, but for servicing this would not be possible because the impact of repair service is not reversible. The block effect (whether the test fell in block 1 or 2) would then be a reflection of the reproducibility of the measurements over a prolonged time period based on data from vehicle 2; reproducibility is not always good for particulate emissions which seem to be affected by atmospheric conditions.

2.10 However, as a result of the vehicle 2 breakdown, it was not possible to follow the original test sequence. This in turn could potentially have lowered the statistical significance of inter-vehicle comparisons. In the original design, vehicle 2 was to be tested several times in block 2 without service. In the actual test sequence, vehicle 2 without a catalyst was tested twice before reconditioning and 11 times after reconditioning in block 2. As a result, block effects were not considered in data analysis since, with the exception of revised sequence tests 18 and 23, vehicle service correlated exactly with the block number (namely, unserviced vehicles were tested in block 1 and serviced vehicles in block 2), and including the block effect would have resulted in double-counting. The last set of five tests (revised sequence test numbers 39 to 43) using vehicle 2 were added later to test the effect of installing a catalytic converter and are not part of the matrix generated by the Design-Expert software for factorial design.

Table 2.4: Measurement Results

OS	*RS*	*VN*	*Fuel*	*Lubricant*	*Repair*	*CO* *g/km*	*HC* *g/km*	NO_x *g/km*	CO_2 *g/km*	*PM* *g/km*	*FC* *km/l*
1	1	3	Dhaka	JFC 3%	Before	25	23	0.07	43	1.15	15
2	2	1	Dhaka	SMO 3%	Before	8.1	8.0	0.07	46	0.35	28
3	3	1	Ref	2T 3%	Before	10	8.8	0.09	50	0.21	26
4	4	2	Dhaka	2T 3%	Before	7.4	7.3	0.27	50	0.27	27
4	30	2	Dhaka	2T 3%	After	11	7.2	0.06	53	0.24	25
5	5	1	Dhaka	2T 8%	Before	5.0	7.4	0.08	44	0.38	31
6	6	3	Dhaka	JFC 3%	Before	25	25	0.05	37	1.06	15
7	7	2	Ref	JFC 3%	Before	10	10	0.27	49	0.20	23
7	31	2	Ref	JFC 3%	After	16	10	0.05	49	0.19	21
8	8	3	Dhaka	SMO 8%	Before	25	23	0.03	43	2.67	15
9	9	2	Dhaka	JFC 8%	Before	6.8	8.2	0.16	45	0.56	28
9	32	2	Dhaka	JFC 8%	After	12	7.2	0.04	49	0.29	26
10	10	2	Ref	2T 8%	Before	6.9	8.2	0.19	48	0.40	27
10	33	2	Ref	2T 8%	After	15	8.0	0.04	48	0.24	23
11	11	3	Ref	SMO 3%	Before	23	28	0.11	43	1.51	14
12	12	3	Ref	JFC 8%	Before	22	25	0.12	42	1.67	15
13	13	3	Ref	JFC 8%	Before	25	27	0.1	45	1.7	13
14	14	3	Dhaka	SMO 8%	Before	25	22	0.08	44	2.5	15
15	15	1	Ref	SMO 8%	Before	7.6	9.2	0.08	50	0.6	25
16	16	3	Ref	JFC 3%	After	17	18	0.1	48	0.79	17
17	17	3	Dhaka	JFC 8%	After	16	14	0.06	49	1.17	19
18	18	2	Ref	SMO 8%	Before	6.3	9.1	0.15	51	0.85	25
18	34	2	Ref	SMO 8%	After	13	7.8	0.04	47	0.63	25
19	19	3	Dhaka	JFC 8%	After	16	15	0.05	54	1.3	18
20	20	3	Dhaka	2T 3%	After	17	16	0.09	51	0.88	18
21	21	1	Dhaka	JFC 3%	After	3.6	7.8	0.11	50	0.33	29
22	22	3	Ref	2T 8%	After	16	18	0.1	50	1.02	17
23	23	2	Ref	2T 3%	Before	11	9.0	0.15	48	0.32	24
23	35	2	Ref	2T 3%	After	18	9.4	0.04	45	0.16	22
24	36	2	Dhaka	2T 8%	After	13	7.1	0.03	48	0.45	26
25	37	2	Dhaka	SMO 3%	After	14	8.0	0.03	47	0.45	24
26	24	1	Ref	2T 8%	After	3.2	7.8	0.12	52	0.31	28
27	38	2	Dhaka	JFC 3%	After	14	7.6	0.03	46	0.19	25
28	25	1	Dhaka	SMO 8%	After	1.6	8.3	0.09	53	0.76	28
29	26	3	Ref	SMO 8%	After	15	17	0.12	52	1.39	17
30	27	1	Ref	JFC 8%	After	3.5	9.0	0.21	56	0.53	25
31	28	3	Ref	JFC 3%	After	15	19.9	0.14	51	0.74	16
32	29	1	Ref	SMO 3%	After	5.4	9.2	0.08	59	0.41	25
33	39	2	Dhaka	SMO 3%	After	14	7.0	0.04	44	0.34	26
34	40	2 cat	Dhaka	SMO 3%	After	11	3.6	0.02	65	0.26	25
35	41	2 cat	Dhaka	SMO 8%	After	8.1	2.9	0.01	69	0.24	26
36	42	2 cat	Dhaka	SMO 3%	After	13	3.6	0.01	67	0.30	23
37	43	2	Dhaka	SMO 3%	After	15	6.7	0.02	44	0.3	26

Notes: OS original sequence; RS revised (actual) sequence; VN vehicle number; FC fuel consumption; Ref 1998 Indian reference gasoline; JFC low smoke lubricant meeting JASO FC; SMO straight mineral oil; “2 cat” vehicle number 2 equipped with an oxidation catalyst; all tests on vehicle 2 were originally designed to be “before” repair.

2.11 The results from smoke opacity measurements are shown in Table 2.5. All the results using vehicle 2 were obtained after the essential "reconditioning" described in paragraph 2.8.

Table 2.5: Opacity Measurements

Vehicle No.	*Lubricant*	*Fuel*	*Idle % opacity*	*Free acceleration % opacity*	*Servicing status*
3	Straight 8%	Reference	90	99.9	Before
3	Straight 3%	Dhaka	80	99.9	Before
1	Straight 8%	Reference	7	80.8	Before
3	2T 3%	Reference	22 to 30	47	After
3	2T 8%	Reference	32	49	After
2	2T 3%	Reference	2 to 3	20 to 26	After
2	2T 8%	Reference	2 to 3	30 to 32	After
1	2T 3%	Reference	0.8 to 1	45 to 48	After
1	2T 8%	Reference	2 to 3	53 to 56	After
1	Straight 3%	Dhaka	2 to 3	40 to 46	After
1	Straight 8%	Dhaka	6 to 8	54 to 58	After
2	Straight 3%	Dhaka	3 to 4	40 to 46	After
2	Straight 8%	Dhaka	7 to 9	72 to 81	After
3	Straight 3%	Dhaka	48 to 54	99.9	After
3	Straight 8%	Dhaka	80 to 85	99.9	After

Data Analysis

2.12 The 40 tests in which no catalyst was used were analyzed first, corresponding to revised sequence test numbers 1 to 39 and 43. For the "base case" to be used in defining the equation specification for regression analysis, the combination of fuel, lubricant, and vehicle parameters that gave the lowest particulate emissions was selected—vehicle 2 after repair, 2T oil at 3 percent, and reference gasoline.

2.13 All of the independent variables were entered as dummies except for RS (revised sequence or revised test number), including the lubricant oil level for which there were only two levels. The independent variables entered in the equation are summarized in Table 2.6. RS was checked to see if there were time-related changes reflecting atmospheric conditions or instrument operations. As will be shown below, RS was found to be statistically significant only in the case of NO_x.

Table 2.6: Independent Variables in the Regressions

Parameter	*Description*
V1	1 if the vehicle is 1 before repair, 0 otherwise
V2	1 if the vehicle is 2 before repair, 0 otherwise
V3	1 if the vehicle is 3 before repair, 0 otherwise
V1S	1 if the vehicle is 1 after repair, 0 otherwise
V3S	1 if the vehicle is 3 after repair, 0 otherwise
L1	1 if the lubricant is straight mineral oil, 0 otherwise
L3	1 if the lubricant meets JASO FC specifications, 0 otherwise
Q2	1 if the lubricant quantity is 8%, 0 if 3%
G1	1 if gasoline is from Dhaka, 0 if it is 87 RON gasoline from India
RS	numbers ranging from 1 to 43 corresponding to the test number in the actual experimental program executed

2.14 The regressions were run in EViews. The dependent variables were entered in linear and log form. In the linear form, the effects of the independent variables would be additive, and in the log form they would be proportionate. Residuals were obtained and the Jarque-Bera and Durbin-Watson statistics were computed. The Jarque-Bera statistic is a measure of skewness and kurtosis, with a normal distribution giving a Jarque-Bera statistic of zero. This was checked to determine whether the residuals were normally distributed as a test of equation misspecification. The Jacque-Bera statistics were compared between the linear and log forms, and the smaller of the two was selected for the final selection of the equation specification, everything else (such as Durbin-Watson and multiple correlation coefficients) being comparable. Lower Jarque-Bera statistics were obtained for the linear form of CO and CO_2, and log of PM, hydrocarbons, $NO_{x,}$ and fuel economy.

2.15 The Durbin-Watson statistics were used to check whether the residuals showed departure from randomness with respect to sequence. Generally, the Durbin-Watson statistic is used to test for the presence of first-order autocorrelation in the residuals of a regression equation where the data are ordered by time. The test compares the residual for time period t with the residual for time period t-1 and develops a statistic that measures the significance of the correlation between these successive comparisons. The statistic has a range of 0 to 4, with a midpoint of 2 (near 2, the null hypothesis is accepted). The null hypothesis is that there is no significant correlation, which would support the hypothesis that there is no significant equation misspecification. Where the Durbin-Watson statistics were found to be very low, the models are not presented in this report.

2.16 The models were initially fitted with all main effects, and then insignificant terms were successively deleted until the model contained only those independent variables that were statistically significant using a two-sided significance test of size 5 percent. (A 5-percent test is one in which the null hypothesis—that is, the identified variable has no additional effect on emissions—would be rejected in 5 percent of tests even if it were true.) Two-sided tests were used because there did not seem to be a basis for predetermining the sign of the expected impact of various parameters examined. Because step-wise deletion does not guarantee the inclusion of all the relevant independent variables, the rejected variables were added back individually and also in groups at the last stage to see if their t-statistics increased. The multiple correlation coefficients were high in all cases.

2.17 By nature of the formulation of the regression equations, the regression results indicate deviations from the base case. If the independent variable is not statistically significant, then it would mean that the emission levels are no different from the base case. For example, if the coefficient multiplying L3 is not statistically different from zero, then it would mean that the emission levels do not change if the lubricant is changed from 2T oil to a low-smoke lubricant meeting the JASO-FC specifications.

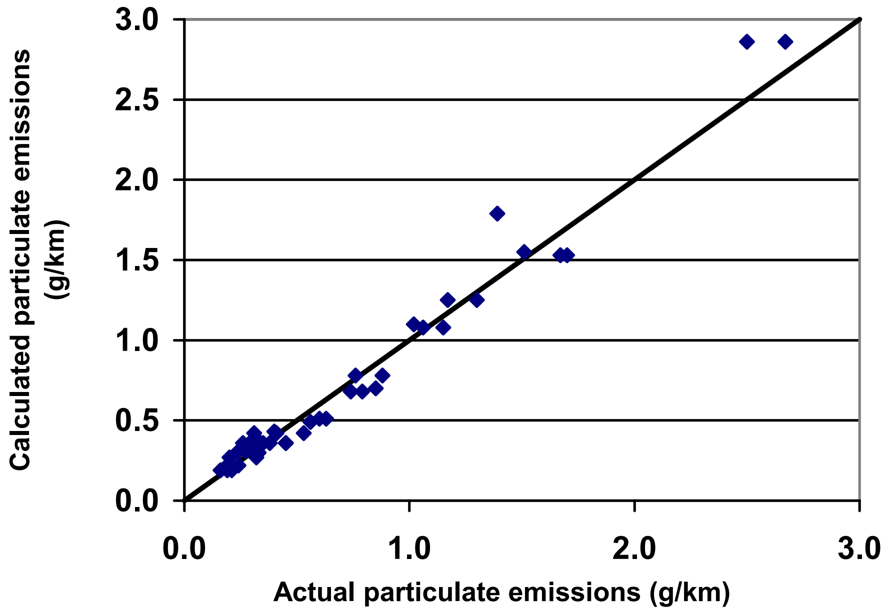
Mass Particulate Emissions

2.18 The results for PM emissions are given in Table 2.7. The base case gives PM emissions of 0.19 g/km. The emissions from vehicle 3 before repair were nearly five times higher than those for vehicle 2 after reconditioning. Repairing vehicle 3 reduced PM emissions by less than 30 percent, and the mass emissions remained substantially higher than those of unserviced vehicles 1 and 2. Although vehicle 2 went through only reconditioning rather than a full service, this seems to have had a considerable impact on particulate emissions, resulting in a decrease of 40 percent. In the case of vehicle 1, repairing actually increased emissions by a third. Increasing the concentration of lubricant from 3 to 8 percent increased emissions by 61 percent, and using straight mineral oil instead of 2T oil also increased emissions by about the same amount. It is not possible to judge whether the relationship between the quantity of lubricant and mass particulate emissions is linear based on only two points. Using gasoline from Dhaka rather than the gasoline purchased in India increased emissions by 14 percent. A comparison of measured and calculated particulate emissions is given in Figure 2.1.

Table 2.7: Log PM Emission Model Specification

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*	$10^{(coefficient)}$
Constant	-0.72	0.028	-25.9	0.0000	0.19
V2 (vehicle 2)	0.14	0.037	3.9	0.0005	1.39
V3 (vehicle 3)	0.69	0.034	20.4	0.0000	4.92
V1S (V1 after service)	0.13	0.038	3.3	0.0023	1.34
V3S (V3 after service)	0.55	0.035	15.7	0.0000	3.53
G1 (Dhaka gasoline)	0.06	0.024	2.4	0.0200	1.14
L1 (straight mineral oil)	0.21	0.026	8.3	0.0000	1.63
Q2 (8% lubricant)	0.21	0.024	8.8	0.0000	1.61
Mean dependent variable		-0.26	Durbin-Watson statistic		2.33
Dependent variable standard deviation		0.33	Jarque-Bera statistic		1.79
R-squared		0.96	F-statistic		109
Standard error of regression		0.07	Probability (F-statistic)		0.0000

Figure 2.1: Comparison of Measured and Calculated Particulate Emissions



2.19 An interesting finding is that, while lubricants meeting JASO FC are known to produce much less smoke than regular 2T oil based only on mineral oil, the so-called "low smoke" oil showed no difference in terms of mass particulate emissions. It is clear from the above findings that the mechanical condition of the vehicle has the most significant impact on particulate emissions.

Hydrocarbon Emissions

2.20 The base case had hydrocarbon emissions of 9 g/km. There was little difference in emissions between vehicle 1 and vehicle 2, and repairing or reconditioning had no impact. Vehicle 3 had substantially higher emissions, as much as three-fold before repair and two-fold even after repair, compared to the other two vehicles. There was essentially no impact from the quality or quantity of lubricant, although using low-smoke lubricant gave slightly more emissions, and increasing the amount of lubricant, if anything, led to a slight decline in hydrocarbon emissions. Unlike particulate emissions, the use of gasoline from Dhaka gave about 15 percent lower emissions. The results are shown in Table 2.8.

Table 2.8: Log Hydrocarbon Emission Model Specification

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*	*$10^{(coefficient)}$*
Constant	0.96	0.008	114.3	0.0000	9.03
V3 (vehicle 3)	0.48	0.012	41.1	0.0000	3.02
V3S (V3 after service)	0.31	0.012	26.2	0.0000	2.02
L3 (low smoke oil)	0.02	0.009	2.1	0.0470	1.04
Q2 (8% lubricant)	-0.02	0.008	-2.9	0.0071	0.95
G1 (Dhaka gasoline)	-0.08	0.008	-8.9	0.0000	0.84
Mean dependent variable		1.1	Durbin-Watson statistic		2.15
Dependent variable standard deviation		0.2	Jarque-Bera statistic		6.69
R-squared		0.99	F-statistic		451
Standard error of regression		0.03	Probability (F-statistic)		0.0000

Carbon Monoxide Emissions

2.21 In the case of CO, the linear form gave better results than did the log form. The results are given in Table 2.9. The base case gave CO emissions of 15.5 g/km. Vehicle 2 after reconditioning was one of the dirtier vehicles, and in fact reconditioning increased CO emissions substantially, by about 40 percent. All of the independent variables except lubricant type were found to be significant. Vehicle 3 before the service was again the worst polluter. The type of lubricant had virtually no impact on CO emissions. Using 8 percent lubricant actually decreased CO emissions, as did using the gasoline from Dhaka compared to the reference gasoline.

Table 2.9: CO Emission Model Specification

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*
Constant	15.5	0.53	29.0	0.0000
V1 (vehicle 1)	-6.50	0.81	-8.1	0.0000
V2 (vehicle 2)	-6.35	0.71	-8.9	0.0000
V3 (vehicle 3)	10.13	0.67	15.1	0.0000
V1S (V1 after service)	-10.70	0.75	-14.2	0.0000
V3S (V3 after service)	1.78	0.68	2.6	0.0128
Q2 (8% lubricant)	-1.54	0.44	-3.5	0.0015
G1 (Dhaka gasoline)	-1.03	0.45	-2.3	0.0281
Mean dependent variable		13.4	Durbin-Watson statistic	2.21
Dependent variable standard deviation		6.7	Jarque-Bera statistic	1.31
R-squared		0.97	F-statistic	128.3
Standard error of regression		1.37	Probability (F-statistic)	0.0000

Nitrogen Oxide Emissions

2.22 The results are presented in Table 2.10. The base case had NO_x emissions of 0.05 g/km. Lubricant, in terms of quality or quantity, was found to have no impact on NO_x emissions. Servicing vehicles 1 and 3 increased emissions by 40 percent and 17 percent, respectively. Reconditioning, however, decreased emissions from vehicle 2 nearly five-fold. For vehicles 1 and 3, servicing seems to improve the combustion efficiency (CO is reduced significantly for both vehicles), and hence the combustion temperature will be higher, giving more NO_x. For vehicle 2 the opposite appears to hold—reconditioning gave higher CO, seemingly indicating lower combustion efficiency, and hence lower peak temperatures and less NO_x. Running on gasoline from Dhaka reduced emissions by a quarter.

2.23 The regression was also run including RS. RS was found to be statistically significant, with a coefficient of –0.0105. This would mean that NO_x emissions steadily fell by more than 60 percent from the beginning to the end of the experimental program. Since much of this "trend" might merely reflect the 11 tests conducted (RS 30-39 and 43) on reconditioned vehicle 2, the equation specification that included RS was not kept.

Table 2.10 Log NO_x Emission Model Specification

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*	$10^{(coefficient)}$
Constant	-1.35	0.049	-27.43	0.0000	0.045
V1 (vehicle 1)	0.32	0.079	4.03	0.0003	2.08
V2 (vehicle 2)	0.68	0.069	9.73	0.0000	4.74
V3 (vehicle 3)	0.29	0.065	4.45	0.0001	1.95
V1S (V1 after service)	0.46	0.073	6.31	0.0000	2.90
V3S (V3 after service)	0.36	0.066	5.44	0.0000	2.28
G1 (Dhaka gasoline)	-0.14	0.044	-3.15	0.0035	0.73
Mean dependent variable		-1.11	Durbin-Watson statistic		2.02
Dependent variable standard deviation		0.28	Jarque-Bera statistic		0.52
R-squared		0.80	F-statistic		22.5
Standard error of regression		0.13	Probability (F-statistic)		0.0000

Carbon Dioxide Emissions and Fuel Economy

2.24 CO_2 emissions give an indication of fuel economy as well as combustion efficiency. For the same amount of fuel burned, the lower the combustion efficiency, the higher the emissions of CO and hydrocarbons, and correspondingly the lower the emissions of CO_2. As in the case of CO, the linear form of the equation gave a lower Jarque-Bera statistic for the residuals, although the difference between log and linear forms was small. The results are given in Table 2.11. The base case had CO_2 emissions of 48 g/km. Only the vehicle type had an impact on CO_2. Vehicle 3 had the lowest CO_2 emissions, and servicing increased CO_2 emissions for both vehicles 1 and 3.

Table 2.11: CO_2 Emission Model Specification

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*
Constant	47.6	0.56	85.0	0.0000
V3 (vehicle 3)	-5.3	1.12	-4.7	0.0000
V1S (V1 after service)	6.6	1.28	5.1	0.0000
V3S (V3 after service)	3.2	1.12	2.8	0.0072
Mean dependent variable		48.1	Durbin-Watson statistic	1.36
Dependent variable standard deviation		4.27	Jarque-Bera	0.53
R-squared		0.67	F-statistic	23.9
Standard error of regression		2.57	Probability (F-statistic)	0.0000

2.25 Since CO_2 emissions expressed in g/km reflect both the extent of conversion of hydrocarbons to CO_2 and fuel economy, and it is difficult to disengage the two effects, regressions were also run on the calculated fuel economy expressed in km/liter. The results are shown in Table 2.12. Vehicle 3 had the lowest fuel economy, increasing by 17 percent after the service. Servicing had no impact on vehicle 1, but decreased the fuel economy of vehicle 2 by 8 percent. The use of gasoline from Dhaka was found to give higher fuel economy. However, it should be stressed that fuel economy was calculated from the measurements made; hence, these findings should be interpreted with caution.

Table 2.12: Log Fuel Economy Model Specification

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*	$10^{(coefficient)}$
Constant	1.35	0.007	189.90	0.0000	22.5
V1 (vehicle 1)	0.054	0.011	5.1	0.0000	1.13
V2 (vehicle 2)	0.032	0.009	3.4	0.0017	1.08
V3 (vehicle 3)	-0.225	0.009	-25.2	0.0000	0.60
V1S (V1 after service)	0.050	0.010	5.0	0.0000	1.12
V3S (V3 after service)	-0.141	0.009	-15.6	0.0000	0.72
Q2 (8% lubricant)	0.017	0.006	2.8	0.0076	1.04
G1 (Dhaka gasoline)	0.045	0.006	7.6	0.0000	1.11
Mean dependent variable		1.34	Durbin-Watson statistic		1.94
Dependent variable standard deviation		0.11	Jarque-Bera statistic		0.80
R-squared		0.98	F-statistic		188
Standard error of regression		0.018	Probability (F-statistic)		0.0000

Catalytic Converters

2.26 As mentioned earlier, the impact of installing an oxidation catalyst was not part of the original experimental design. As a result, there are not enough measurements to be able to perform meaningful statistical analysis. The last 14 tests (revised sequence test numbers 30 to 43) were analyzed to examine the impact of the catalytic converter on (reconditioned) vehicle 2. The independent variables in this case were L1, L3, Q2, and G1; in addition, another independent variable that was equal to 1 when the catalyst was used (and zero otherwise) was included. The analysis for NO_x gave a Durbin-Watson statistic of only 0.86, indicating the presence of significant first-order autocorrelation in the residuals. Similarly, the residuals for CO_2 gave a Durbin-Watson statistic of 1.07, again indicating the presence of significant first-order autocorrelation and hence some systematic misspecification. Therefore, the results for NO_x and CO_2 are not be presented.

2.27 The results for PM, hydrocarbon, and CO emissions are shown in Table 2.13 to2.15. The multiple correlation coefficients were relatively low for PM and CO emissions. The catalyst had the most significant impact on hydrocarbon emissions, as indicated by the high t-statistic, and the largest fall in the emissions level (more than 50 percent). The hydrocarbon model also gave the highest multiple correlation coefficient. These preliminary data do suggest that the oxidation catalyst decreased PM and CO emissions. However, it should be stressed that the sample size was small for studying the impact of installing an oxidation catalyst, and these findings should not be overinterpreted but, rather, treated with caution.

Table 2.13: Log PM Model Specification, Effect of Catalyst

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*	$10^{(coefficient)}$
Constant	-0.69	0.049	-14.2	0.0000	0.20
L1 (straight mineral oil)	0.27	0.069	3.9	0.0030	1.85
Q2 (8% lubricant)	0.16	0.061	2.6	0.0249	1.45
Catalyst	-0.20	0.083	-2.5	0.0332	0.62
Mean dependent variable		-0.54	Durbin-Watson statistic		2.80
Dependent variable standard deviation		0.16	Jarque-Bera statistic		0.48
R-squared		0.66	F-statistic		6.53
Standard error of regression		0.11	Probability (F-statistic)		0.010

Table 2.14: Log Hydrocarbon Model Specification, Effect of Catalyst

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*	$10^{(coefficient)}$
Constant	0.97	0.018	54.9	0	9.42
Q2 (8% lubricant)	-0.06	0.018	-3.3	0.0087	0.88
G1 (Dhaka gasoline)	-0.10	0.020	-4.9	0.0006	0.80
Catalyst	-0.33	0.021	-15.7	0	0.46
Mean dependent variable		0.81	Durbin-Watson statistic		1.88
Dependent variable standard deviation		0.17	Jarque-Bera statistic		1.07
R-squared		0.97	F-statistic		121
Standard error of regression		0.03	Probability (F-statistic)		0.0000

Table 2.15: CO Model Specification, Effect of Catalyst

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*
Constant	17.05	0.80	21.29	0.0000
Q2 (8% lubricant)	-2.47	0.79	-3.13	0.0108
G1 (Dhaka gasoline)	-2.93	0.89	-3.30	0.0080
Catalyst	-2.62	0.96	-2.72	0.0215
Mean dependent variable		13.51	Durbin-Watson statistic	1.29
Dependent variable standard deviation		2.54	Jarque-Bera statistic	3.33
R-squared		0.77	F-statistic	11.06
Standard error of regression		1.39	Probability (F-statistic)	0.0016

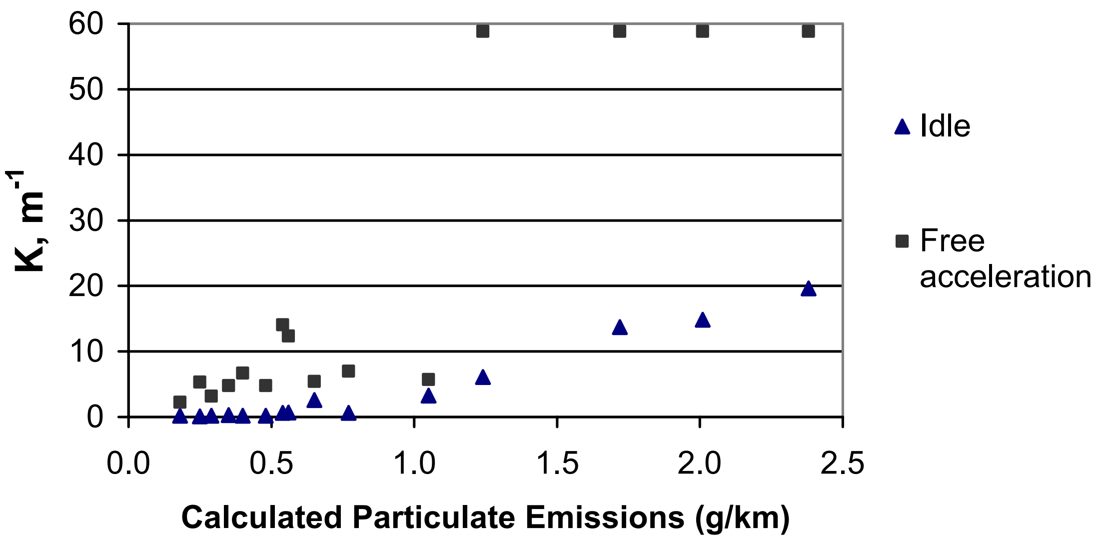
Comparison with Smoke Measurements

2.28 A measure of the smoke concentration in the exhaust, in terms of the number of species that scatter light, can be found from the *K* value:

$$K = -\ ln(1-\text{opacity}) \div l$$

where l is the optical pathlength of the instrument. Setting l equal to 5.1 cm, K has been computed and plotted against mass particulate emissions in g/km computed from the model equation. The results are shown in Figure 2.2.

Figure 2.2: Comparison of Relative Smoke Concentration and Particulate Mass Emissions



2.29 There is some correlation between smoke measurements and mass particulate emissions, but the relationship is weak. For idle smoke, there is a reasonable relationship above particulate emissions of 1 g/km. Below 1 g/km, idle smoke measurements converted to K are not discriminating. Under free acceleration, the smoke meter reached saturation above 1 g/km. Below 1 g/km, the data are scattered and there is no clear relationship with mass particulate emissions.

2.30 If indeed the relationship between smoke measurements and mass particulate emissions is weak below 1 g/km, smoke measurements can identify only gross emitters. This will present a problem in an emissions inspection program if the majority of vehicles fall under the category of less than 1 g/km, or even 0.5 g/km. However, before any conclusions are drawn, more data are needed with more rigorous checks on data accuracy and reproducibility. For example, it is important to bear in mind that the Celesco smoke meter was designed for use with diesel vehicles. It has been widely used for gasoline vehicles in recent years but there have been debates about its validity because the size distribution of particles from four-stroke gasoline engines is considerably smaller than that from diesel, and this in turn has a major impact on the scattering of laser light. As a result, diesel vehicles tend to give better reproducibility than gasoline smoke measurements do. However, the majority of particles from two-stroke vehicles are liquid droplets, and there are essentially no data on droplet size distribution and whether the size distribution of particles from two-stroke engines will have a positive or negative impact on the correlation between smoke opacity and mass particulate emissions.

Conclusions

2.31 This work represents the first statistically designed experimental program for measuring mass emissions from the two-stroke engine three-wheelers that are typical of the commercial vehicles driven in South Asia. While the breakdown of vehicle 2 and its subsequent unplanned "reconditioning" compromised the statistical design somewhat, there are a number of interesting observations. Given the small sample size, however, these observations should not be overinterpreted.

- The mass PM emissions were high, ranging from 0.16 to 2.7 g/km, and averaging 0.7 g/km. In constructing an emissions inventory for PM, the contribution from two-stroke gasoline engines may be substantial if these numbers are used. However, the nature of particles is fundamentally different between diesel and gasoline two-stroke engines; therefore, it may be misleading to add them together. For the purpose of developing an emissions mitigation strategy, it may make more sense to keep these two categories of PM emissions separate.
- The mechanical condition of the vehicle (reflecting both vehicle technology and maintenance) had by far the greatest impact on emissions. Vehicle 3, the oldest vehicle, had the highest emissions for PM, hydrocarbons, and CO.
- Mass particulate emissions followed the expected trend, with the exception of vehicle service—that is, using straight mineral oil, increasing the concentration of lubricant added, and using gasoline purchased in Dhaka (which is often adulterated with kerosene) increased emissions.
- The impact of varying the quality of gasoline and quality and quantity of lubricant on other pollutants was mixed. The quality of lubricant had no impact on hydrocarbon, CO, and NO_x emissions. Increasing the concentration of lubricant lowered hydrocarbon and CO emissions, as did the use of gasoline from Dhaka, which in addition lowered NO_x emissions.
- Repairing typically, but not always, lowered emissions.
- The emissions of NO_x were inversely correlated with those of PM, hydrocarbons, and CO when comparing different vehicles. This would make sense since the higher the combustion temperature, the higher the production of NO_x and the lower the amount of residual PM, hydrocarbons, and CO found in the exhaust gas.
- The correlation between smoke and mass PM emissions was poor below 1 g/km. Since this may be a function of the instrument used to measure smoke, more work should be carried out to check this correlation. If the poor correlation continues to be confirmed with additional data, then the effectiveness of mandating that in-use vehicles meet smoke emissions standards is questionable.
- There was no evidence that JASO-FC grade "low smoke" lubricants lower mass PM emissions, although they have been demonstrated to reduce visible smoke. For the purpose of protecting public health, it is probably sufficient to ban straight mineral oil but not necessarily mandate JASO-FC grade lubricants.

- Factorial design is a powerful tool for designing experiments because it helps to reduce the total number of runs. However, most software packages for factorial design use only analysis of variance to analyze the data. This is limiting because analysis of variance performs only “yes/no” categorization of variables and can miss out on important insights. In this study, factorial design was used to construct the test matrix but regression techniques were used to analyze the data. Given that the same vehicles are tested a number of times before and after servicing, the use of panel data techniques may be considered in the future programs of this nature so as to fully exploit the statistical insights that can be obtained.

3

Mechanics Training

3.1 Mechanics who service baby-taxis play an important role in combating vehicular emissions. Without adequately trained and equipped mechanics, proper maintenance of baby-taxis would not be possible, thus potentially resulting in gross emissions. The drivers also turn to mechanics for advice, including recommendations on the use of lubricant.

3.2 Recognizing the important role baby-taxi mechanics play in vehicular emissions control, the first phase of this ESMAP program targeted several hundred of these mechanics for training. The training program was organized by a local environmental non-governmental organization (NGO), Society for Urban Environmental Protection (SUEP), and Uttara Motors Limited, the sole importer and retailer in Bangladesh of two-stroke engine three-wheelers from Bajaj Auto in India. Some of the mechanics at Uttara Motors have been sent to India for training by Bajaj Auto. The mechanics training program was held in Dhaka from April 11 to 26, 2000; a total of 427 mechanics participated in the program.

Mobilization of Trainees

3.3 SUEP compiled a list of some 700 mechanics who were asked about their interest in attending the training program. Those who expressed interest were assigned to sessions convenient for them. The mechanics were told about the nature of the training program and assured that they would be compensated for the loss of income during training in the amount of Tk 100.

3.4 The information collected from the participants showed that most repair workshops were makeshift places where fewer than five people worked. Many even lacked a street address. At present, there are no training schools for mechanics in Dhaka. The learning process takes place through apprenticeship with a master. The trainees start at a young age, sometimes as young as ten. Nearly 60 percent of the mechanics in the program were below the age of 25. Three-quarters of them had less than five years of schooling. However, what they lacked in terms of formal education was compensated for by many years of apprenticeship. About 60 percent of the trainees had 7 or more years of experience.

Training Program

3.5 The participants were trained in groups of about 20 for 3 hours at a time by Uttara Motors mechanics. Technical training materials, translated into Bangla, were given to each trainee. The content of the program is given in Table 3.1. In the training room there were several stripped-down two-stroke and four-stroke engines for three-wheelers. The manner of instruction was interactive, with the trainers asking questions and the mechanics responding. The mechanics were forthcoming in volunteering information that indicated why emissions may remain high even after "normal maintenance service." For example, several mentioned that when spark plugs were replaced, second-hand spark plugs from other vehicles, rather than new spark plugs, were used.

3.6 Basic personal information (described in paragraph 3.4) about each trainee was collected, including:

- place of work
- years of experience
- level of education
- number of vehicles handled per day
- type of repair and servicing performed and their frequencies.

3.7 The practical demonstration showed two baby-taxis, the first fueled with gasoline containing 10 percent crankcase oil, the second with gasoline containing 3 percent 2T oil. The difference in the level of smoke emissions between the two vehicles was dramatic. The first vehicle emitted so much smoke that the participants began to walk away from the vehicle, whereas the second vehicle showed little visible smoke.

3.8 Post-training evaluation was conducted in which a random sample of 20 mechanics trained in the program were invited to a discussion meeting lasting more than an hour. Most of the mechanics could answer questions about emissions from old vehicles, especially the role of better quality lubricant and proper maintenance. However, they also pointed out some practical problems in implementing emission reduction measures. For example, they mentioned the lack of ready availability of 2T oil. A fairly large percentage of the mechanics expressed interest in longer-term in-depth maintenance training and their willingness to share some of the cost of such a program.

Table 3.1: Mechanics Training Program

Topics	*Duration*
Air Pollution from two-stroke engine vehicles	30 minutes
• What is air pollution?	
• Causes of excess exhaust smoke emissions from three-wheelers	
• Comparison of smoky oil with smokeless oil	
• Cost-effectiveness of 2T oil versus crankcase engine oil	
• Health effects of air pollution	
• Action needed for reduction of excess smoke	
Preventive maintenance	60 minutes
• Inspection before maintenance	
• Checking and maintenance: air cleaner, spark plugs, carburetor jet, needle pin, float, air screw, contact breaker (CB) point gap	
• Decarbonizing and checking cylinder, piston ring, cylinder head and silencer muffler	
Schedule of maintenance	15 minutes
Advice for drivers	15 minutes
• Inspection and maintenance	
• Quality and quantity of lubricant	
• Quality of gasoline	
• Good driving habits	
Collection of personal data	10 minutes
Practical demonstration	45 minutes
• Smoke emissions from two-stroke engine vehicles with different gasoline/lubricant mixtures	
• Engine components (two- and four-stroke)	
Distribution of certificates	5 minutes

4

Auto Clinic

4.1 Behavioral change among drivers to the use of the correct quantity and quality of lubricant and regular vehicle maintenance can achieve appreciable reductions in emissions from baby-taxis. Disseminating information and persuading stakeholders of the benefits of such behavioral change are essential parts of a long-term strategy for urban air quality management. One of the principal stakeholders in the transport sector in Dhaka is baby-taxi drivers. A major campaign, called an "auto clinic," was mounted from October 10 to November 9, 2000 in order to:

- create awareness of transport-related air pollution (especially from baby-taxis) and possible control measures among the stakeholders
- build human and institutional capacity to conduct future programs for the reduction of air pollution from motor vehicles
- create a database on:
  - the mechanical state of the in-use vehicles
  - personal profiles of drivers, including their health and socioeconomic status, and perceptions of air pollution and vehicular emissions
  - emission levels of "as-received" and serviced vehicles
- disseminate information on good practice in lubricant use and vehicle maintenance, and create a groundswell of support for the introduction of 2T lubricants for baby-taxis

This auto clinic drew heavily from similar programs in Delhi and elsewhere.

Auto Clinics in Other Asian Countries

4.2 The largest auto clinic held to date in South Asia was the two-wheeler inspection and maintenance clinic held in Delhi between November 11 and December 2, 1999. This auto clinic was financed by the United States Agency for International Development (USAID) and ICICI Group, and was run principally by the Society of Indian Automobile Manufacturers (SIAM) whose members include all the major two-wheeler manufacturers. The Government of the Union Capital Territory of Delhi authorized SIAM personnel to issue "pollution under control" (PUC) stickers free of charge to vehicle owners and stationed traffic police personnel at the clinic sites. Because vehicles in Delhi are required to obtain PUC stickers four times a year, the issuing of free PUC stickers to those vehicles that passed the emissions test—the PUC requirement being that the idle CO emission level should be less than 4.5 percent—provided an incentive for participating in the clinic. The vehicles were tested for hydrocarbon and CO emissions, and some were also tested for smoke, although only the CO emission results were used to judge pass/fail for emissions.

4.3 The Delhi clinic was accompanied by considerable publicity in the media. The program was opened by the Chief Minister of Delhi, and a number of celebrities, dignitaries, and government officials made appeals to the public to participate in the clinic. More than 66,000 vehicles participated in the clinic.

4.4 Valid test results were obtained on 56,000 vehicles. Of those, 94 percent passed the idle CO test immediately. Those that failed had the air-to-fuel ratio adjusted and were tested again. The majority of the failing vehicles (88 percent) passed the idle CO test after the air-to-fuel ratio adjustment. Those that failed had the spark plug and air filter cleaned and adjusted, after which more than half passed. A total of 150 vehicles continued to fail even after the two rounds of "repair" service.

4.5 Following the success of the Delhi clinic, SIAM has run clinics in other cities. In Hyderabad in October 2000, 10,000 vehicles including two- and three-wheelers, gasoline and diesel passenger cars, and diesel jeeps participated in a clinic funded in part by USAID. In the same month, SIAM also ran a clinic for 3,000 three-wheelers in Chennai. Earlier in November 1999, a clinic for passenger cars was held in Mumbai.

4.6 Elsewhere in Asia, auto clinics for two-wheelers, sponsored by ESMAP, were held in Bangkok, Thailand in May and July of 2000. About 3,000 vehicles took part in the two auto clinics, each of which lasted three days. Detailed questions were asked of vehicle owners to collect socioeconomic information as well as their views on air pollution. Vehicles were tested for CO, hydrocarbons, and smoke opacity. Vehicles that did not meet the emission standards for in-use vehicles in Thailand, shown in Table 4.1, were given simple tune-up service and tested again. About 83 percent of motorcycles that participated in the auto clinics were of two-stroke engine design, and the overall pass rate was 76 percent. Nearly three-quarters of the drivers were using low-smoke lubricants. Minor tune-ups had a measurable impact on emissions, decreasing the number of gross emitters and correspondingly increasing the number of cleaner vehicles.

Table 4.1: Emission Standards for In-Use Vehicles in Thailand

Type of vehicle	*Idle CO*	*Idle hydrocarbons*	*High idle smoke opacity*
Two-wheeler	4.5%	10,000 ppm	30%
Three-wheeler	4.5%	8,000 ppm	30%

Notes: Although only two-wheelers participated in the auto clinic, the emission standards for three-wheelers are given for comparison with the results obtained in the Dhaka auto clinic. Smoke opacity is in Hartridge smoke units. ppm parts per million.

Dhaka Auto Clinic

4.7 The auto clinic was organized by SUEP and Uttara Motors, with technical assistance from Bajaj Auto in Pune, India. SUEP was in charge of logistical arrangements and publicity. Uttara Motors handled the technical components of the clinic. The Bangladesh Road Transport Corporation (BRTC) Depot was selected for the site and a waterproof tent was set up. Cards were issued entitling baby-taxi drivers to participate in the program. Forty percent of the cards were distributed through the Autorickshaw Drivers' Welfare Union, and another 40 percent through the Autorickshaw Owners' Association. The remaining 20 percent of the cards were given out near and at the site of the clinic. A pamphlet in Bangla on emissions, health effects, lubricants, and maintenance was printed and given to each participating baby-taxi driver. For publicity and greater involvement of various stakeholders, a discussion meeting on the auto clinic was planned halfway through the clinic.

4.8 A Wager smoke meter (model 6500) and a Horiba automotive emission gas analyzer (model MEXA 324J) for CO/hydrocarbons were purchased for the auto clinic. They are described in Annex 1.

4.9 The participants were given several incentives, including 2 liters of gasoline and 60 ml of 2T lubricant; a free medical checkup; and a sticker stating that they had participated in the clinic. Most were also given T-shirts, which said in Bangla, "To reduce air pollution, use 2T oil and take care of the engine." The organizers of the clinic obtained agreement from the Dhaka Metropolitan Police that baby-taxis displaying the pass sticker would not be stopped by the police for visual emission inspection. These visual emissions inspections are carried out at random by the traffic police and offenders are fined Tk 200. This was perhaps the greatest incentive of all, and toward the end of the auto clinic program, drivers queued for hours to obtain the sticker. Those who did not succeed in obtaining the pass sticker the first time around came back after repairing the vehicle and obtaining the correct gasoline/lubricant formulation. Some drivers went to the extreme of coming to the clinic with no lubricant added to gasoline to minimize smoke emissions.

4.10 Throughout the clinic, visual demonstrations of the impact of lubricant use and vehicle technology on emissions were given. To this end, two two-stroke engine three-wheelers of comparable age were hired and run on different gasoline/lubricant combinations. One was fueled with gasoline containing 10 percent crankcase oil, and the other contained 3 percent 2T oil. In addition, a new four-stroke engine three-wheeler was provided by Uttara Motors. The four-stroke engine vehicle showed no visible smoke even upon acceleration. Last, two-stroke engine baby-taxis converted to run on compressed natural gas (in a project financed by the Canadian International Development Agency) and lubricated by 2T oil were brought in on a few days.

4.11 Posters on emissions and health effects of air pollution, and drawings of two- and four-stroke engines were on display throughout the clinic. Mobil Jamuna Lubricants Limited opened a kiosk displaying 2T lubricant and gave away key rings.

4.12 Each participant was taken through a questionnaire, which is given in Annex 2. The questionnaire consisted of four sections: (1) driver's health status, filled in by a doctor; (2) environmental perceptions and socioeconomic status, filled in by two interviewers; (3)

condition and use of the vehicle, filled in by mechanics from Uttara Motors; and (4) emission testing results, filled in by two technicians involved in exhaust emissions measurements.

4.13 The doctor gave a medical checkup, and a limited amount of medication was given out to those found ill. For a number of drivers, this was the first time they had been examined by a doctor. Each vehicle was inspected by a Uttara Motor mechanic first and the findings were recorded, then emission measurements were taken. The measurements were carried out by two very experienced laboratory technicians from the Bangladesh Atomic Energy Commission. They in turn trained four staff members from the Department of Environment (DOE) on how to measure exhaust emissions.

4.14 A set of pass/fail criteria were established to select those vehicles that would be subject to simple tune-up procedures for further testing. The criteria are based on Thai standards with some modifications and are shown in Table 4.2.

Table 4.2: Criteria for Pass/Fail at the Auto Clinic

Idle CO	*Idle hydrocarbons*	*High idle smoke opacity*
4.5%	10,000 ppm	30%

The Uttara Motors mechanic explained the findings of the initial vehicle check to the driver, and in most cases the drivers watched the exhaust measurements being taken. In each test, three opacity readings were taken and the average was compared to the 30 percent limit set to judge pass/fail. For CO and hydrocarbons, only one reading each was taken.

4.15 The vehicles that failed were subject to the following set of maintenance procedures as needed:

- air filter cleaning
- spark plug cleaning and gap adjustment
- carburetor air screw adjustment
- carburetor jet cleaning and jet needle position adjustment
- cleaning and resetting of contact breaker points in vehicles not using electronic ignition. This step was performed only in the older vehicles that used the “contact breaker” type of ignition system. It was not required in newer vehicles (post-1996/97) in which the electronic ignition system was introduced by the vehicle manufacturer.

Initially, some vehicles had their silencer assembly and/or engine decarbonized, but this proved to be too time-consuming and was discontinued. Likely causes of failure were explained to the driver and advice on repair was given. The pamphlet on air pollution, health, lubricant use, and vehicle maintenance was explained to the driver while the vehicle was being serviced and during the survey.

4.16 At first, vehicles that failed to pass the second time were to be subjected to further servicing. However, this was found too time-consuming, partly because more than 40 percent of the vehicles did not pass even the second time around. Vehicle servicing and testing were therefore stopped after the second test. After the first 655 vehicles, all of the vehicles, whether they passed or not, were checked by mechanics, serviced as needed, and tested for emissions for the second time.

Discussion Meeting

4.17 The discussion meeting on the auto clinic was held on October 22, 2000 at the BRTC Depot. The discussants included Dhaka Divisional Commissioner A.R. Khan (Chief Guest); BRTC Chair Azmal Chowdhry (Special Guest); Rehana Akhter, Project Director for the Air Quality Management Project; Azizul Huq, President of the Autorickshaw Drivers' Welfare Union; Haji Fazlul Haque, President, Autorickshaw Owners' and Workers' Association; and fuel and lubricant marketers.

4.18 The discussants stressed the need for regular vehicle maintenance and the sale of 2T lubricant in sealed packages rather than in open jugs as is currently done in order to exercise greater control over the quality of lubricants sold. Commissioner Khan emphasized the need for creating more awareness among vehicle owners, drivers, and the public.

Results of Data Collection

4.19 The first two sections of the survey sought to collect information on the health and socioeconomic indicators for baby-taxi drivers and their perceptions of air pollution in Dhaka, including the contribution of baby-taxis.

Personal Profile of Baby-Taxi Drivers

4.20 A summary of health statistics and personal and work-related information for the baby-taxi drivers is shown in Table 4.3. The majority of the drivers were in their 20s and 30s. The average workday was nearly 12 hours long. Many of the drivers were found to be in poor health. About two-fifths of the drivers undergoing medical examination were found to be ill. Most had never had their blood pressure measured. Five cases of hypertension, unknown to the sufferers, were diagnosed. The average number of sick days on which they could not work was found to be surprisingly high, at seven days per month. Some of the drivers were very sick, and could not work a regular five or six days a week—instead, they worked until they could not work any more. Most of them suffered from malnutrition with a low body weight, an average of 53 kilograms (kg) for a height of 163 cm. Many were found to suffer from worm infections. Because air pollution is expected to affect the lung function, pulmonary function testing was performed using a spirometer. The readings obtained were indeed low, considerably below the population average of 500 ml. However, the number of cases of chronic asthma was found to be rather low. It is likely that those with asthma leave the profession. This could also explain why only a quarter of the drivers were over the age of 35. By the time they reach 35, they are possibly unfit to carry on working as drivers.

Table 4.3: Health and Work-Related Parameters for Baby-Taxi Drivers

Parameter	*Value*	*Minimum*	*Maximum*
Age, years	32±8	18	75
Number of children	2.4±1.4	0	9
Experience, years	10±6	0	40
Driving hours per day	12±2	4	18
Height, cm	163±6	140	192
Weight, kg	53±8	35	83
Sick days per month	7.0±2.7	0	20
Blood pressure, systolic, mm Hg	125±9	90	170
Blood pressure, diastolic, mm Hg	71±5	60	100
Lung function, milliliters	372±76	150	700

mm Hg millimeters of mercury, a unit for pressure. Lung function values are spirometer readings and represent the forced vital capacity.

4.21 With respect to education, two-thirds of the drivers had no education and were illiterate. This means that providing written materials would not be effective for disseminating information and raising awareness. Another 17 percent had 5 years or less of education and could barely read or write. Only 16 percent could be considered literate.

4.22 About one-tenth of the drivers owned vehicles, ranging in number from 1 to 5 and averaging 1.2. The remaining 90 percent of the drivers hired vehicles at an average daily rate of Tk 205 (US$3.80 at the exchange rate in November 2000 of Tk 54 to the dollar). Monthly average net income (after paying all expenses) was Tk 4125 (equivalent to US$76 at the time). The correlations between monthly income and the parameters that are expected to affect income are shown in Table 4.4. Not surprisingly, being sick reduced income. The number of hours worked per day and years of experience did not seem to strongly determine income. Vehicle owners earned more, with income increasing with increasing number of vehicles owned.

Table 4.4: Correlations between Income and Other Parameters

Parameter	*Income*
Number of sick days	-0.15
Vehicle is driven by owner	0.27
Number of vehicles owned	0.18
Number of hours driven per day	0.03
Number of years of experience	0.05

Attitudes toward Ownership and Ban on Two-Stroke Engines

4.23 On questions regarding the ownership of baby-taxis and ability to pay, the following responses were obtained:

- 96 percent wanted to buy a baby-taxi.
- 94 percent had some savings.
- 94 percent were willing repay loans in installments to buy baby-taxis.
- 94 percent said they were able to provide some type of collateral or personal guarantee for loans.

4.24 Predictably, 94 percent were opposed to the banning of baby-taxis. Asked what they would like to do if two-stroke engine baby-taxis were banned in Dhaka, the following responses were received:

- 88 percent would like to drive a regular car taxi.
- 8.5 percent would like to drive a Mishuk (four-stroke engine baby-taxi).
- 13 (out of 1,000) would do whatever job they can find.
- 4 would drive baby-taxis in some other city.
- 2 would pull rickshaws.
- 1 would go to a village and farm.

Perception of Air Pollution

4.25 Ten questions concerned the drivers' perceptions of air pollution from the baby-taxis they drive. The answers are summarized below:

- 81 percent believed that air pollution was a growing and serious problem.
- 92 percent believed baby-taxis were causing air pollution.
- 99 percent said the owners should pay more attention to reducing pollution from baby-taxis.
- 98 percent believed that the drivers should pay more attention to pollution reduction.
- 35 percent stated that some members of their household had respiratory problems.
- 44 percent stated that some members of their household had health problems due to air pollution.
- 31 percent stated that they had to incur expenditures to treat sickness due to air pollution.
- 20 percent stated that they had lost income due to air-pollution-related sickness.
- 97 percent agreed with the suggestion that pollution from baby-taxis caused health problems.

Emission Test Results

4.26 The mechanics examining the "as-received" vehicles described most as being in "good" condition. Only five drivers were found to be using 2T oil. The rest were all using straight mineral oil. The average amount of lubricant added was 8 percent. The emission levels of as-received baby-taxis as well as of 699 vehicles that had been serviced are shown in Table 4.5. Some 619 vehicles failed to meet the criteria set forth in Table 4.2. CO and hydrocarbon levels were surprisingly low. Failure to pass depended largely on smoke emission levels as a result. Eighty passing vehicles were serviced and tested again. The emissions test results after the minor tune-ups described above are included in the column with the heading "after service." Of those serviced and tested again, close to two-thirds still failed to meet the emission limits.

Table 4.5: Emission Levels of Baby-Taxis

Parameter	*As-received*	*After service*
% CO	1.1±1.4	1.2±4.0
Minimum/maximum	0.0 / 6.7	0.0 / 6.6
ppm HC	3420±1950	3250±1920
Minimum/maximum	68 / 14,000	130 / 13,700
% Opacity	40±24	40±21
Minimum/maximum	0 / 98	0 / 100
Number of vehicles	988	699

Note: Emission levels are average values followed by one standard deviation. The numbers of as-received vehicles is smaller than 1,000 because only valid emission readings were considered for analysis.

4.27 The distributions of emission levels of the three pollutants are shown in Figure 4.1 through 4.3. The distributions were skewed, particularly for CO and hydrocarbons. The Jacque-Bera statistics were 1594, 1041, and 96 for CO, hydrocarbons and opacity, respectively.

4.28 The CO and hydrocarbon emission readings were lower and, in the case of CO, much lower than expected. At the two-wheeler clinic conducted in Delhi in December 1999, the average CO of as-received vehicles was 3.4 percent. Comparable or higher figures would be expected in Dhaka, since maintenance of two-wheelers, typically privately owned, tends to be better, and vehicles in Delhi are required to submit to emissions inspections every three months.

4.29 The instruments were checked repeatedly with calibration gases. Sample measurements with motorcars yielded values that seemed reasonable (and much higher than those obtained on baby-taxis). One explanation is that the lower values arose from leakage in the emission systems in most of the vehicles. The leaks would cause dilution of the exhaust gases, resulting in low levels of CO and hydrocarbon emissions. If this hypothesis is correct, then smoke readings could also be affected and the actual smoke levels might be even higher than what was measured.

Figure 4.1: Distribution of CO Emissions Readings

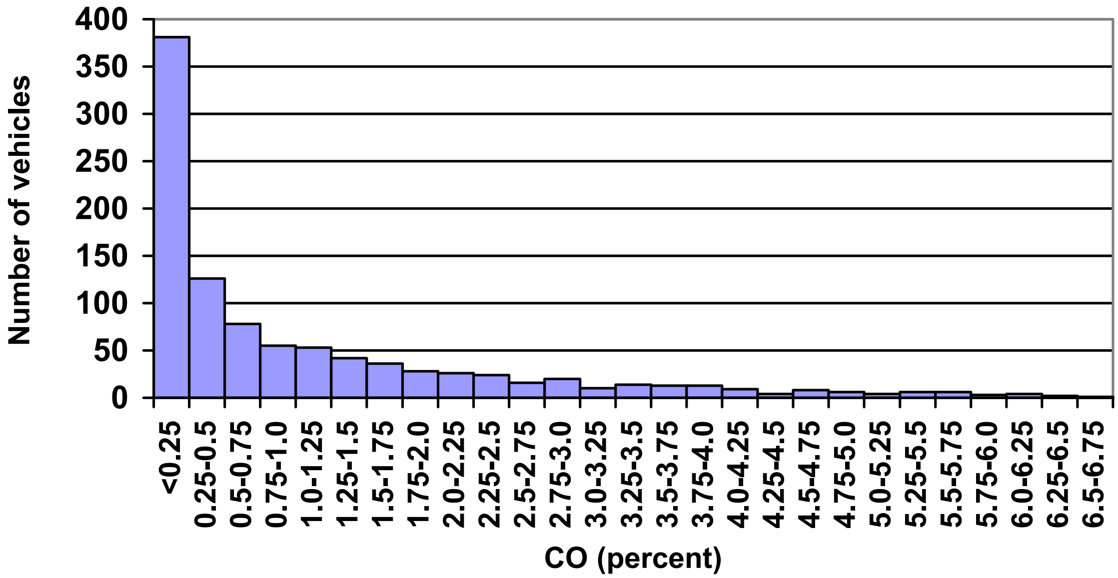


Figure 4.2: Distribution of Hydrocarbon Emissions Readings

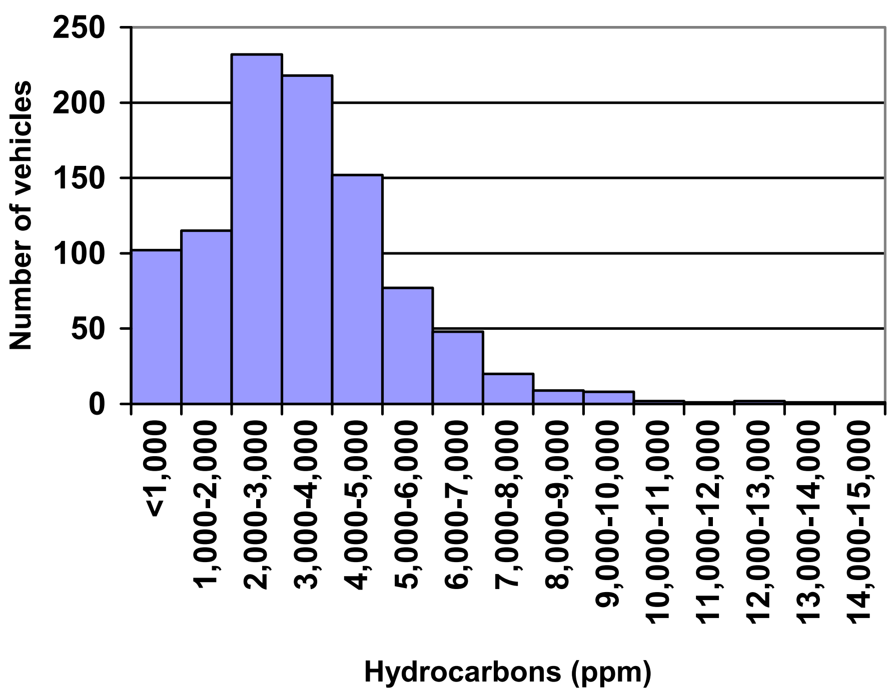
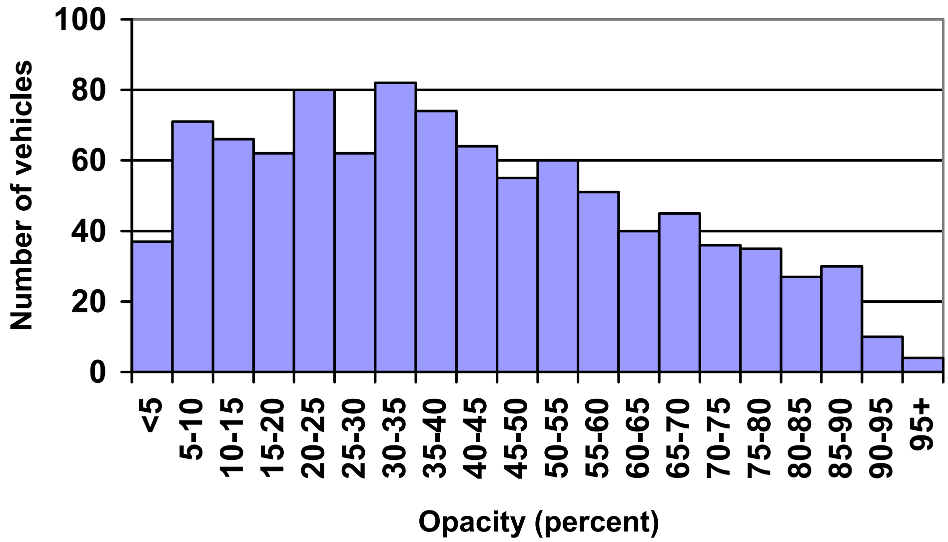


Figure 4.3: Distribution of Opacity Readings



4.30 Clinics subsequently held by SIAM in India on three-wheelers also showed CO and hydrocarbon emission levels comparable to or lower than those measured on two-wheelers. Another possible explanation is that local mechanics tend to change or readjust the carburetor jets for commercial three-wheelers to reduce the fuel flow, thereby making the air-fuel mixture leaner. While this may lead to loss of power, the fuel efficiency improves and the CO and hydrocarbon emission levels can be lower. However, merely adjusting the fuel mixture to run leaner is unlikely to cut emissions by a factor of three.

4.31 The impact of minor tune-up for the 699 vehicles serviced and retested is summarized in Table 4.6. The impact was most pronounced in the case of smoke emissions, which decreased for nearly three-quarters of the vehicles tested. In the case of CO, there were a number of cases where emission levels were low to begin with and increased after the service. In relative percentage terms these increases were large, resulting in a large average relative percentage increase for the vehicle fleet as a whole.

Table 4.6: Impact of Service

Parameter	*CO*	*Hydrocarbons*	*Smoke opacity*
Percentage of vehicles for which emissions decreased after service	53	55	72
Largest increase, absolute[1]	5.8%	5810 ppm	59%
Largest decrease, absolute	5.8%	7390 ppm	87%
Average decrease, relative %[2]	-46	-2	13
Median decrease, relative %	5	3	20
Average decrease, absolute	0.10%	103 ppm	9.7%

[1]The differences in measurements before and after the service are shown. [2]Negative decreases mean that the values in question increased after the service.

Factors that Affect Emissions

4.32 The dependence of CO, hydrocarbon, and smoke emissions of the as-received vehicles on the model year, type of lubricant, lubricant quantity, and the mechanical condition of the vehicle was examined. Opacity (percent), CO (percent), and hydrocarbons (ppm) were the dependent variables. Information on the following potential independent variables was collected and tested.

1. Vehicle model year
   Emissions are expected to decrease with increasing model year (lower for newer vehicles).
2. Alternative to 1 above, model year transformed to five 1/0 dummies as pre-1994, 1994, 1995, 1996, 1997 (and 1998+ as the base case).
3. Vehicle ownership (1 if the driver is the owner, 0 otherwise)
   Non-owners are expected to have less incentive to maintain their vehicles, and hence emissions are expected to be lower for vehicles driven by owners.
4. Air filter choked (1/0 dummy)
   Emissions are expected to be higher if the air filter is choked.
5. Air filter damaged (1/0 dummy)
   Emissions are expected to be higher if the air filter is damaged.
6. Carburetor “tampered or damaged” (1/0 dummy)
   Emissions are expected to be higher if the carburetor is tampered or damaged. However, upon inquiry, it transpired that signs of ad hoc repair were recorded as “carburetor tampered or damaged.” As shown below, “tampered” or “damaged” vehicles gave lower emissions.
7. Oil from the oil chamber leaking (1/0 dummy)
   Emissions were found to be affected when this oil was leaking. While there is no obvious explanation linking the leakage of this oil to higher emissions, this problem may be symptomatic of other mechanical problems which in turn could cause higher emissions.
8. Ignition coil damaged
   Emissions are expected to be higher if the ignition coil is damaged.
9. Time lapsed since last service (in months)
   Emissions are expected to be higher with increasing time lapse since last service.
10. Percent lubricant
    Emissions are expected to increase with increasing lubricant quantity.
11. Type of lubricant (1 for straight mineral oil, 0 for 2T)
    Emissions are expected to be lower if 2T oil is used.
12. Time lapsed since the silencer was decarbonized/repaired/replaced (in months)
    Emissions are expected to increase with increasing time lapse. The correlation coefficient between 9 and 12 was 0.20.

13. Spark plug fouled (1/0 dummy)
    Emissions are expected to be higher if the spark plug is fouled.
14. Air filter removed (omitted, see below)
    Emissions are expected to be higher if the air filter has been removed.
15. Crankcase damaged (omitted, see below)
    Emissions are expected to be higher if the crankcase is damaged.
16. Ignition cable damaged (omitted, see below)
    Emissions are expected to be higher if the ignition cable is damaged.
17. Silencer decarbonized (omitted, see below)
    Emissions are expected to be lower if the silencer has been decarbonized recently.
18. Silencer replaced (omitted, see below)
    Emissions are expected to be lower if the silencer has been replaced recently.
19. Spark plug worn out (omitted, see below)
    Emissions are expected to be higher if the spark plug is worn out.

4.33 The explanatory variables 14–19 were omitted because more than 99 percent of the vehicles fell into one of the two dummy categories (either 0 or 1). The only exception to this practice of omitting an independent variable because there was not enough variation in the sample was lubricant type, where only 5 baby-taxis were found to be using 2T oil. However, given the expected impact of lubricant quality on smoke emissions, this parameter was kept. A one-sided significance test of size 10 percent (t-statistic of 1.29) was performed on the remaining variables except 6 and 8. A two-sided significance test of size 10 percent (t-statistic of 1.64) was performed on 6 and 8. In the case of the carburetor being tampered or damaged, it was not clear if the "tampered" or "damaged" carburetor identified had actually been repaired recently (in which case emissions would be expected to be lower), or if in some cases the carburetors were actually damaged (in which case emissions would be expected to be higher). Similarly, there were indications that "damaged" ignition coils could also mean ignitions coils with signs of ad hoc repair. A weak criterion (10 percent test) was used for statistical significance so as not to miss linkages between emissions and various parameters.

4.34 The regressions were run in EViews. The model was constructed using White heteroskedasticity-consistent standard errors and covariances to allow for possible non-constancy of variance in the error terms arising from equation misspecification. The dependent variables were entered in linear and log form. The latter was chosen in case the impacts of the different independent variables were not additive in terms of emissions they produced so that non-linear functions might represent this effect.

4.35 Residuals were obtained and the Jacque-Bera statistic was computed as a test of equation misspecification. In all cases, the statistic was highly significant, suggesting that the set of independent variables available was inadequate to account for the systematic variation in the dependent variables. The Jacque-Bera statistics were compared between the linear and log cases, and the smaller of the two was selected for the final selection of the equation specification (the multiple correlation coefficients were similar for the two cases).

The lower values were obtained for the linear form of opacity, log of CO, and linear form of hydrocarbons, giving Jacque-Bera statistics of 36, 28, and 379, respectively.

4.36 Each equation was constructed by first inserting all of the independent variables, and eliminating those that did not meet the significance criterion. The dropped variables were then added back one by one as well as in groups to see if their t-statistics became significant. The equations were often quite unstable, with t-statistics changing as a result of one variable being added or eliminated.

4.37 The correlation of each dependent variable with each independent variable was examined and the results are shown in Table 4.7. As will be shown below, the independent variables with relatively high correlation coefficients were found to be statistically significant in regression equations.

Table 4.7: Correlations among Various Variables

Parameter	*CO*	*Hydrocarbons*	*Opacity*
CO	1.000		
Hydrocarbons	0.633	1.000	
Opacity	0.074	-0.020	1.000
Air filter choked	0.028	0.068	0.047
Air filter damaged	-0.015	-0.107	0.008
Carburetor “tampered” or “damaged”	-0.086	-0.182	-0.023
Oil chamber leaking	-0.028	-0.028	0.048
Ignition coil damaged	-0.018	0.022	-0.065
Time since last service	0.017	0.121	0.041
Lubricant, percent	0.017	0.020	0.137
Lubricant type	-0.036	0.010	-0.085
Model year	0.030	0.060	0.005
Owner	0.033	0.021	-0.037
Time lapsed since silencer last serviced	0.074	0.085	0.108
Spark plug fouled	0.017	-0.055	0.165

4.38 In all cases, the overall goodness of fit was low, with a multiple correlation coefficient lower than 10 percent. Such low values show that independent variables were able to account for very little of the variation in the dependent variable. This, together with other indications discussed below, strongly suggests that there are omitted variables that affect emissions, and that might alter the statistical significance of the variables listed below as well as of those that had been dropped. The final set of results for each pollutant is given below.

Opacity

4.39 The model for opacity is given in Table 4.8. Although there were only 5 baby-taxis using 2T oil, and hence the evidence presented here is weak, the type of lubricant used was found to have the most significant impact on opacity. Switching from straight mineral oil to 2T oil is forecast to reduce opacity by 24 percent. Reducing the quantity of lubricant from 8 percent to 3 percent would be expected to lower opacity by $1.7 \times 5 = 8.5$ percent. The impact of all drivers switching to 2T oil and adding only 3 percent lubricant was estimated using the above model specification. Comparing fitted values from the original data values and estimated coefficients with those obtained from the new values (setting lubricant type to 2T and lubricant quantity to 3 percent for all baby-taxis) reduced the average opacity from 41 percent to 29 percent for the fleet as a whole.

Table 4.8: Model Specification for Opacity

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*
Constant	6.3	5.0	1.3	0.21
Air filter choked	7.2	2.7	2.6	0.0087
Air filter damaged	6.9	2.9	2.4	0.017
Carburetor “tampered”/ “damaged”	-3.3	1.9	-1.7	0.08
Oil chamber leaking	2.7	1.7	1.6	0.12
Ignition coil “damaged”	-3.4	1.6	-2.2	0.03
Lubricant percent	1.7	0.46	3.7	0.0003
Lubricant type	-23.6	3.6	-6.5	0
Owner	-3.9	2.5	-1.5	0.12
Time lapse since last silencer service	2.0	0.77	2.6	0.01
Spark plug fouled	18.7	3.0	6.3	0
Mean dependent variable	40.5	Durbin-Watson statistic		2.0
Dependent variable standard deviation	23.8	F-statistic		7.4
R-squared	0.078	Probability (F-statistic)		0
Standard error of regression	23			

Note: 895 included observations, 106 excluded observations.

4.40 Choked and damaged air filters had a comparable impact on opacity. Fouled spark plugs were found to increase smoke emissions significantly. The amount of time lapsed since the silencer was last serviced showed the expected trend of increasing emissions with increasing lapsed time. Leaking oil chambers were associated with higher emissions, but “damaged” ignition coils were associated with lower emissions; the mechanics may have used the word “damaged” loosely, similar to the case of “damaged” carburetors. Vehicles driven by owners showed lower emissions.

4.41 The multiple correlation coefficient was the highest for opacity, but even here, it was lower than 10 percent. This aspect is discussed more below.

Carbon Monoxide

4.42 The CO emission data were found to be highly skewed. Only variables 6 and 12 were found to be statistically associated with emissions, as shown in Table 4.9. The multiple correlation coefficient was the lowest among the three pollutants.

Table 4.9: Model Specification for Ln CO

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*
Constant	-0.64	0.11	-5.6	0
Carburetor "tampered or damaged"	-0.20	0.11	-1.8	0.077
Time since last silencer service	0.074	0.046	1.6	0.11
Mean dependent variable	-0.72	Durbin-Watson statistic		1.83
Dependent variable standard deviation	1.37	F-statistic		3.24
R-squared	0.0070	Probability (F-statistic)		0.039
Standard error of regression	1.36			

Note: 923 included observations, 78 excluded observations.

Hydrocarbons

4.43 When all the available data were included, the log form gave a lower Jarque-Bera statistic than the linear form. The results are given in Table 4.10.

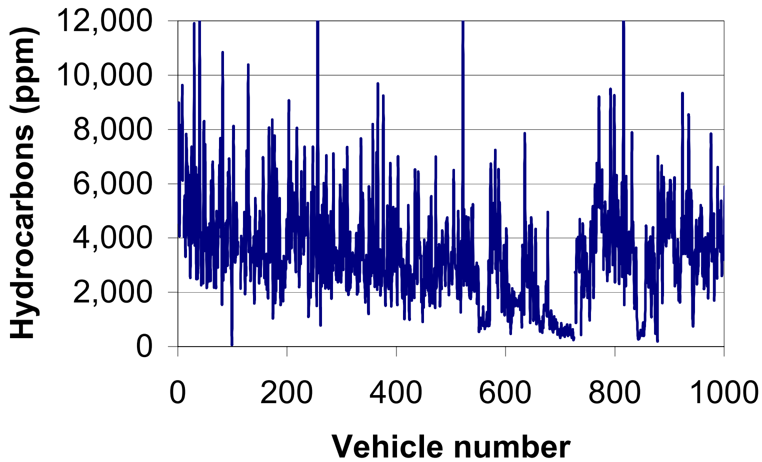
Table 4.10: Model Specification for Ln Hydrocarbons

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*
Constant	8.1	0.058	139	0
Air filter damaged	-0.16	0.051	-3.1	0.0019
Carburetor "tampered or damaged"	-0.24	0.053	-4.5	0
Time lapsed since last service	0.037	0.011	3.3	0.0012
Time lapsed since last silencer service	0.030	0.021	1.5	0.14
Mean dependent variable	7.9	Durbin-Watson statistic		0.78
Dependent variable standard error	0.70	F-statistic		13
R-squared	0.057	Probability (F-statistic)		0
Standard error of regression	0.68			

Note: 878 included observations, 122 excluded observations after adjusting endpoints.

4.44 Variables 5, 6, 9, and 12 were found to be associated with hydrocarbon emissions. While the multiple correlation coefficient is higher than that for CO, the Durbin-Watson statistic was extremely low. A time-series plot of hydrocarbon measurements was examined to see if the data were randomly distributed or exhibited a pattern.

Figure 4.4 Hydrocarbon Emission Readings in the Order Taken



4.45 Figure 4.4 shows a gradual decline in hydrocarbon emissions up to vehicle number in the neighborhood of 700 instead of random readings. This pattern in turn suggests that the hydrocarbon meter was not functioning properly. One explanation is that, although the so-called hang-up test was conducted regularly to test for system contamination, the filters required more frequent replacement. The filters were changed once, and the timing of the filter replacement was not recorded. It seems plausible that the filters were changed just before the hydrocarbon readings returned to the previous level (around the time vehicle 720 was tested). Communication with Horiba, the instrument manufacturer, indeed confirmed that the most likely explanation is that the filters gathered oils and particles, preventing the hydrocarbons from reaching the detector, but that this would not affect CO readings.

4.46 In light of the above, a regression was next run on a sub-set of the original data, taking the first 500 data points to minimize the impact of this downward trend. The results are shown in Table 4.1. Using only the first 500 data points, the linear form gave a lower Jacque-Bera statistic, albeit still high at 379.

4.47 Only two variables, the same as those found in the case of CO, were now found to be statistically significant. This coincidence may be related to the fact that the same meter measured hydrocarbons and CO. The Durbin-Watson statistic was much improved.

Table 4.11: Revised Model Specification for Hydrocarbons

Variable	*Coefficient*	*Standard error*	*t-Statistic*	*Probability*
Constant	4218	197	21.5	0
Carburetor tampered/damaged	-789	201	-3.9	0.0001
Time lapsed since silencer service	147	85	1.7	0.08
Mean dependent variable	3861	Durbin-Watson statistic		1.87
Dependent variable standard deviation	1846	F-statistic		11.6
R-squared	0.051	Probability (F-statistic)		0.000012
Standard error of regression	1802			

Note: 436 included observations, 64 excluded observations

4.48 While one would expect the vehicle's age to influence emissions, the results were not significant and, in the case of CO, the t-statistic was sizable but negative. This finding of a negative relation between emissions and age must be a result of equation misspecification; it is also possible that some variables were subject to substantial measurement error. Substituting the vehicle's age with dummy variables for different model years yielded statistically insignificant results with both positive and negative signs. The fact that emissions could not be correlated with the model year or age groups further suggests that important parameters that affect emissions are missing from the equation specification.

4.49 To see if some of these discrepancies may be due to measurement uncertainties, the three readings for opacity in the first set of tests were analyzed for variance. The average of standard errors for the three readings for each vehicle (intra-vehicle variation) was 9, while the standard error of average readings for all the vehicles (inter-vehicle variation) was 24. This suggests that the "noise" in the data is relatively large for a given vehicle compared to vehicle-to-vehicle variation, making it difficult to correlate emissions with measurable variables. The reasons for this intra-vehicle variation may include poor miscibility of straight mineral oil with gasoline (possibly resulting in uneven distribution of the lubricant in gasoline) and difficulty in reproducing the same engine condition (engine speed) for the three readings.

Observations and Lessons

4.50 "Auto clinics" are increasingly popular in Asia as a way of educating drivers and raising public awareness about the role each vehicle driver/owner can play in improving urban air quality. These clinics also provide an excellent opportunity to collect data on emission levels from in-use vehicles.

4.51 The analysis of data collected from 1,000 vehicles in Dhaka highlights the following lessons.

- Statistical analysis is a powerful tool for assessing the impact of various parameters on emissions. Such analysis in turn is essential if the Bank's policy recommendations are to be based on sound science. Statistical analysis can help test widely held perceptions, such as that old vehicles pollute much more or low smoke lubricant reduces particulate emission levels. Having data and analysis to support or refute these perceptions is important, especially if stringent regulations (such as banning vehicles older than a certain age, or mandating expensive but low-smoke-producing synthetic lubricants) are being envisaged.

- The statistical framework for the analysis to be undertaken must be set up prior to conducting the auto clinic, so that the necessary data are collected. All too often, there is a tendency to start thinking rigorously about data reduction only after all the data have been collected, by which time it is too late if one or more pieces of crucial data are missing.
- Measurement errors arise from a number of sources and affect statistical analysis. In the Dhaka auto clinic, three main sources of measurement errors seemed to play an important role: (1) handling of the CO/hydrocarbon meter, (2) poor reproducibility in measuring smoke at high idle (multiple readings of CO and hydrocarbons were not taken for each vehicle), and (3) leakage of pollutants before they reached the end of the exhaust pipe. If the last problem were common, it would be very difficult to identify gross emitters, and in fact such a problem would defeat the purpose of an inspection and maintenance program, however well-run. In an inspection and maintenance program, inter-instrument variation is another potential source of significant measurement errors.
- Despite these shortcomings, the results obtained in this auto clinic were in qualitative agreement with the mass emissions data collected at ARAI discussed in Chapter 2. For example, the type and quantity of lubricant had little, if any, effect on CO and hydrocarbon emissions.
- The data collected supported the hypothesis of declining smoke emissions with decreasing lubricant quantity and using 2T oil rather than straight mineral oil. The impact of vehicle age on emissions was much less clear and would need to be investigated further.
- Drivers and mechanics are adept at circumventing the purpose of the emissions testing procedure. Toward the end of the clinic many, if not most, drivers learned from others that in order to “pass,” they would need to reduce the amount of lubricant added. Some even arrived with the vehicle having no lubricant added to the gasoline, an undrivable condition in the long run.There were also factors other than those identified that had a considerable impact on emissions. Since they account for more than 90 percent of total emissions, more work to identify what these factors are would be useful.

5

Toward Legislative Change

5.1 The foregoing chapters have demonstrated that two immediate simple solutions—which would cost little, if any, money—could significantly improve air quality: using the correct type and concentration of lubricant and carrying out regular maintenance. Promoting these "win-win" measures requires building public awareness by disseminating information on the health impact of emissions, and the types of engines, fuel, and lubricant that reduce emissions; making it unacceptable for retail outlets to add excess lubricant to gasoline at the point of sale; and banning the sale of straight mineral oil to be used in vehicles.

5.2 To this end, a workshop on lubricant and gasoline quality was held in Dhaka on November 21, 2000. The workshop was attended by more than 100 people. Among the participants were representatives from various government agencies—the Ministry of Energy and Mineral Resources (MEMR), Ministry of Environment and Forest (MoEF), Ministry of Commerce, Dhaka City Corporation, Bangladesh Road Transport Authority (BRTA), Dhaka Metropolitan Police, Bangladesh Standards and Testing Institution (BSTI); fuel and lubricant manufacturers and marketers; baby-taxi drivers and owners; Uttara Motors; academics and researchers; environmental NGOs; and press reporters.

5.3 There was a unanimous call to ban the sale of straight mineral oil for use in vehicles and to mandate minimal 2T lubricant standards for two-stroke engine vehicles. This position was strongly supported by the Secretary of the Ministry of Energy and Mineral Resources. The participants agreed that monitoring and enforcement of the ban on straight mineral oil was the most crucial next step.

Seminar Program for Lubricant and Gasoline Quality

Topic	*Speaker*	*Affiliation*
Address of welcome	Mizanur Rahman	Joint Secretary, MEMR
Lube oil, gasoline, and air quality	Masami Kojima	World Bank
Address of the Chief Guest	Akmal Hossain	Secretary, MEMR
Vote of thanks	Paul Martin	World Bank
Gasoline and diesel quality: technical and policy issues	A. H. M. A. Majid Rahimi	Director, BPC
Fuel and lube quality in Thailand	Thanin Utawanit	Director of Fuels and Lubricant Research, PTT*
Lube oil: Bangladesh perspective	A. M. N. Alam	Independent Specialist
Fuel and lube quality: Step forward (written submission)	C. S. Mahmood	General Manager, Padma Oil Corporation
Fuel and lube quality: Step forward	M. M. Hossain	Chief Engineer, Mobil Jamuna Lubricants
CNG as a clean fuel for transportation	M. A. Mannan	Chairman, Rupantarita Prakitic Gas Company
Open discussion		
Lubricant and fuel standards	Shafiqur Rahman	Director, BSTI
Vehicular emission standards and the role of DOE	Rehana Akhter	Project Director, Air Quality Management Project, DOE
Enforcement of emission standards and role of BRTA	Mujibur Rahman	Assistant Director, BRTA
Perspectives of the traffic police	Benazir Ahmed	Deputy Commissioner (Traffic), Dhaka Metropolitan Police
Future of baby-taxis	Imdad Hussain	Executive Director, Uttara Motors
Emissions reduction from baby-taxis	Haji Fazlul Hoque	Convenor, Autorickshaw Owners' and Workers' Association
Distribution of 2T lube oil	Zeeshan Saif	Senior Executive, Mobil Jamuna Lubricants
Open discussion		
Concluding session and recommendations	Chair: Nuruddin M. Kasmal	Former Chair, Power Development Board

*PTT Petroleum Authority of Thailand

5.4 During the seminar, there was a dramatic demonstration of the impact of varying the quality and quantity of lubricant as well as vehicle technology on smoke emissions. Two baby-taxis were randomly selected from the street, and tested using gasoline containing 10 percent straight mineral oil and 3 percent 2T oil, respectively. The baby-taxi running on 3 percent 2T oil showed virtually no visible smoke. In addition, one two-stroke engine baby-taxi converted to compressed natural gas (CNG) and two four-stroke engine baby-taxis were on display. The CNG vehicle showed very little smoke, as expected, while the four-stroke engine taxis exhibited essentially no smoke and no smell of hydrocarbons associated with two-stroke engine vehicles.

5.5 The mechanic who went to refuel these vehicles told the audience that he had great trouble purchasing only gasoline with the intention of adding the proper amount of 2T oil himself (in the case of two-stroke engine) or no lubricant (in the case of four-stroke). At several gasoline filling stations, attendants insisted that gasoline had to be sold with (excess) straight mineral oil. This experience illustrates the importance of working closely with gasoline retail outlets in moving toward the practice of using the correct quantity and quality of lubricant.

Seminar Recommendations

5.6 The seminar participants drafted and endorsed the following recommendations. The recommendations were subsequently issued widely. They are reprinted below.

Seminar on Lubricating Oil and Gasoline Quality for Air Quality Improvement in Bangladesh—Recommendations

Lubricant for two-stroke engine vehicles

- Gazette notification of JASO-FB or API-TC as the minimum national standard for 2T lubricant should be issued by March 1, 2001;
- BSTI should develop a transparent process to recognize certification of 2T lubricant by JASO or API accredited laboratories;
- Sale of non-2T lubricant for use in 2T vehicles should be prohibited by MEMR;
- BPC and BSTI should develop a joint program to monitor lubricant quality at retail outlets;
- Marketing companies should make 2T lubricant available for retail purchase in small sealed packages by March 1, 2001;
- MEMR, through BPC and the marketing companies, should prohibit the retail sale of lubricant not in sealed packages from July 1, 2001.

Gasoline

- BPC, BSTI and DoE should develop a joint program to monitor gasoline quality at retail outlets and publish results;
- The marketing companies should also monitor gasoline quality at retail outlets and publish results;
- MEMR should develop a strategy to prevent the adulteration of gasoline;

- MEMR should develop a strategy to increase the octane level of regular gasoline to 87 RON[1].

Diesel

- MEMR should develop a strategy to reduce the sulfur content of diesel to 0.3%.

Emissions control

- DoE should lead a transparent and consultative process to revise in-use vehicle emission standards;
- DoE should develop a program of emissions monitoring with DMP and BRTA.

CNG

- The Government of Bangladesh should develop a strategy to promote the use of CNG in vehicles.

Banning Straight Mineral Oil

5.7 A notification, approved by the Ministry of Energy and Mineral Resources and issued by the Bangladesh Petroleum Corporation, was published on January 13, 2001. The notification, explicitly setting as its objective mitigating smoke emissions from vehicles, prohibited production, blending, import, and marketing of straight mineral oil without additives, and set as minimal standards for lubricants for two-stroke engine vehicles JASO FB or API TC. In addition, it set as minimal standards for lubricants to be used in four-stroke engine vehicles API SC[2] and API CC.

5.8 This notification has officially made it illegal to knowingly sell straight mineral oil to baby-taxi drivers. However, the sale of lubricants in loose containers, such as jugs used to sell lubricants to baby-taxi drivers, is not prohibited, so that monitoring becomes especially important if compliance with these regulations is to be achieved.

5.9 In order to implement and enforce the quality standards for 2T oil, the first condition that must be met is wide availability of 2T oil. Equally important is the cooperation of filling station owners and attendants. The information collected in this ESMAP-funded program showed that, as of 2000, it was actually difficult for baby-taxi drivers to purchase gasoline without the addition of straight mineral oil.

5.10 In October 2001, seven months after the deadline suggested in the seminar recommendations, one lubricant marketer finally launched the sale of 2T oil in 60 ml sachets. If the practice of buying lubricant in 60 ml sachets becomes widespread, then many more drivers will be using the correct quantity and quality of lubricant. There was a launching

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1 The current RON is 80.

2 The API "S" series (SA, SB, SC, SD, and so on) covers engine oils for use in passenger cars and light trucks (mainly gasoline engines), and the "C" series covers oils for use in commercial, farm, construction, and off-highway vehicles (mainly diesel engines). The API SG category was formally adopted in March 1988 and met the requirements of 1989 model year passenger cars. Similarly, the API CE was adopted in 1988 and recommended by all American heavy-duty engine manufacturers. In 1990, it was replaced by API CF-4 for four-stroke engines.

ceremony for the marketing of sachets attended by the State Minister for Energy and two Secretaries. In order to assess the impact of the sale of 2T oil in small sachets and the overall effectiveness of BPC's notification, a second baby-taxi auto clinic was held in December 2001-February 2002 under the auspices of the World Bank's Learning and Innovation Loan, Bangladesh Air Quality Management Project. Under this project, a survey of lubricant use was also conducted in early 2002.

5.11 Establishing suitable regulations, bringing together various stakeholders to uphold the regulations, and raising the awareness of consumers and the general public are all critical components of urban air quality management. This program has illustrated how these steps may be taken, as well as lessons learned in the process of doing so. The progress made in this program will be followed up in other air pollution targeted programs, including the above project and Dhaka Urban Transport Project.

References

Biswas, Swapan Kumar. 1998. "Development of Analytical X-ray Methodologies for Atmospheric Aerosol Studies in Bangladesh." Ph.D. thesis submitted to the Department of Physics, Faculty of Mathematical and Physical Sciences of the Jahangirnagar University, Bangladesh.

Kojima, Masami, Carter Brandon and Jitendra Shah. 2000. Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles. December, Washington, D.C.: World Bank.

MECA (Manufacturers of Emission Controls Association). 1999. "Emission Control of Two- and Three-Wheel Vehicles." Washington, D.C.

Annex 1. Emission Measurements

A1.1 Two instruments were used in the emission measurements. They were the Model 6500 Wager smoke meter and Model MEXA 324J Horiba automotive emission gas analyzer. Their descriptions and operating procedures are given below.

Wager Smoke Meter

A1.2 The meter is manufactured by Robert H. Wager Company in North Carolina, United States. It consists of a sensor head assembly connected by a multi-core cable to a control unit. A light sensor in the head assembly reads the intensity of the light emitted by a pulsed green light emitting diode (LED) passed through a smoke stream emitted by a vehicle. The light intensity depends on the opacity of smoke obstructing the light beam. The sensor readings are relayed to the control unit for display. Proper functioning of the sensor head assembly can be checked by using calibrated filters of known opacity. This meter meets the Society of Automotive Engineers (SAE) J1667 specifications. The sensor head assembly can be placed in appropriate position for opacity measurements with the extension pole provided. The control unit is housed in a lightweight aluminum case. The front panel is a membrane keypad with eight tactile feedback push buttons. It is connected to the sensor head assembly with a single 25-foot multi-core cable. The display is a backlighted alphanumeric liquid crystal display containing 16 characters in two rows. The display prompts the operator through the test sequences. All readouts are accurate to within ±one digit (0.01 percent of full scale). Minimum drift and zero stability are each less than 1 percent per use.

A1.3 The equipment is quite rugged. During the month-long operation of the auto clinic, about 2,000 measurements were taken and virtually no maintenance was needed. Pulsed green LED has a very long life expectancy. Lenses are accessible by simple snap closures and can be easily cleaned. Baffle plates on interior faces of the monitor help maintain cleanliness. All electronics are solid state.

A1.4 The system is powered by a 12 volt sealed lead acid cell, which operates approximately 40 hours before a recharge is required. The battery condition is displayed through a series of colored LEDs. The instrument is portable and well suited for field inspection measurements, as no power connection is needed.

A1.5 The meter comes with an impact printer for the printing of the opacity values. The control unit can store 100 test results and can be connected to a personal computer through an RS232 cable. The software for data transfer is provided.

A1.6 In order to take measurements, the engine gear was set in the neutral position. With the engine idling, the accelerator was stepped on quickly. This was repeated six times to clear the exhaust system. Subsequently, the maximum opacity value read in three successive accelerations was taken. The meter monitors fluctuating opacity at a rapid rate and records the maximum value in a given interval of measurements when put in the snap acceleration test mode.

Horiba Emission Gas Analyzer

A1.7 The analyzer consists of a probe unit and the main instrument. This model can measure up to 20,000 ppm hydrocarbons and up to 10 percent CO. During measurements the probe head is inserted into the exhaust pipe of the vehicle and gases are drawn into the instrument through it. The instrument has a warm-up time of about 5 minutes.

A1.8 The system needs 110-240 volt alternating current 50 hertz power and consumes about 60 watts, requiring power connection that must be arranged for roadside or field inspection. The meter comes with an impact printer for the printing of the CO/HC values. As this printer is connected to an analogue output, only instantaneous values are printed. The results have to be printed after steady values are displaced but before the meter is put on hold.

A1.9 The response time of the instrument is about 15 seconds for the warm instrument. At the end of the day the instrument should be purged with clean air for decontamination of the system and checked by performing a hang-up test. The instrument uses a set of three filters which should be periodically replaced when they can no longer perform their functions efficiently. The repeatability of the meter is better than 5 percent. The instrument has to be periodically calibrated using a gas standard supplied by the manufacturer in a bottle to maintain the quality of measurements. The calibration gas for the auto clinic contained 18,200 ppm propane and 6.9 percent CO, both by volume, the balance being nitrogen.

A1.10 The engine was first accelerated to a moderate speed with no load and maintained for at least 15 seconds before returning to idle speed. While the engine was idling, the probe was inserted 30 cm into the exhaust pipe and the reading was taken after the engine speed stabilized. This procedure was repeated several times until stable readings were obtained.

Annex 2. Baby-Taxi Auto Clinic Questionnaire

Part I Drivers' Health Status

Date	
Interviewer	
Vehicle Reg.	

1.1 Name:

1. 2 Address: **Present** **Permanent**

1. 3 Bio-statistics:

Age	Married	Wives	Children	Dependents	Head of Family
	Y/ N/ D				Y / N

1.4 Experience (years as baby-taxi driver):

1.5 Education (grade):

0	0-5	5-8	8-10	SSC - UP

1.6 Hours driven (each day):

1.7 Health data:

General Appearance:		Clinical:	
Height		Blood pressure	
Weight		Eye sight	
Build		Heart	
Sick days per month		Asthma	
		Years (asthma)	
Lung function test:			

1.8 Diagnosis/Treatment/Comments:

Part II Environmental Perceptions and Socioeconomic Status

Date	
Interviewer	
Vehicle Reg.	

2.1 Do you believe air pollution in Dhaka is a serious and growing problem?

1. Yes 2. No 3. Do not know

2.2 Do you think that baby-taxis are polluting the air?

1. Yes 2. No 3. Do not know

2.3 Do you think that the owners of baby-taxis should pay more attention to reducing pollution from their vehicles, such as by making sure that their vehicles are maintained regularly?

1. Yes 2. No 3. Do not know

2.4 Do you think that drivers of baby-taxis should pay more attention to reducing pollution from their vehicles, such as by learning more about the use of lube oil?

1. Yes 2. No 3. Do not know

Interviewer: High exhaust emissions from baby-taxis are due primarily to inadequate vehicle maintenance and wrong use of lube oil. Give a brief explanation about air pollution causing health problems, especially respiratory symptoms effects (for example, sinus, nose, throat, and/or chest).

Be aware that these symptoms will not include a headache or stomachache unless the respondent has them at the same time.

Then ask the next question:

2.5 What do you consider to be the major cause of respiratory symptoms for you or your household members?

__________1. Air pollution

__________2. Heredity

__________3. Do not know the cause

__________4. Others (specify)………………………………………………..

2.6 Have you or anyone in your household ever had respiratory symptoms?

__________1. Yes (go to Q. 2.8)

__________2. No (go to Q. 2.7)

2.7 If no, are you or anyone in your household suffering any health problems (for example, related to eye, skin, etc.) caused by air pollution?

__________1. Yes (go to Q. 2.8)

_________2. No (go to Q. 2.10)

2.8 Did you spend any money for treatment of this sickness due to air pollution?

_________1. Yes

_________2. No

2.9 Did you lose income because of your sickness?

Interviewer: Lost income means less effective work and inability to work.

________1. Yes

________2. No

2.10 Suppose someone says that pollution from baby-taxis causes health problems? Do you agree?

________1. Yes

________2. No

2.11 Are you the household head?

________1. Yes

________2. No

2.12 Number of members in your household (including you)…………..persons

2.13 Number of working persons in your household…………………….persons

Number of non-working persons in your household………………..persons

2.14 What is your gross income per month? …………………Taka/month

2.15 What is the total gross income of your household (including your spouse and other family members if any) per month? ……………………..Taka/month

2.16 Are you the owner of the baby-taxi you drive?

________1. Yes How many baby-taxis do you own in total? ________

(Go to Q2.22)

________2. No

2.17 How much do you pay for the hire of a baby-taxi? Taka…………./day

2.18 Would you like to buy a baby-taxi?

________1. Yes

________2. No

2.19 Do you have any savings that you can use toward the purchase of a baby-taxi?

________1. Yes .... Taka in total OR

I am saving ....Taka/month.

________2. No

2.20 If you are given a loan to buy a baby-taxi, would you be able to pay the installments regularly?

________1. Yes

________2. No

2.21 Can you find some body to act as guarantor for the loan?

________1. Yes

________2. No

2.22 Some people say that two-stroke engine baby-taxis should be banned in Dhaka because they pollute too much. If you were not a driver of a baby-taxi, would you also support such a ban?

________1. Yes

________2. No

2.23 If baby-taxis with 2-stroke engines are banned, what would you do?

_______1. Go to another city to a drive baby-taxi

_______2. Drive a Mishuk

_______3. Drive a car taxi

_______4. Drive a rickshaw

_______5. Go home and farm

_______6. Do whatever job is available

Part III Condition and Use of the Vehicle

Sl					Date	
REG					Interviewer	

3.1 Type:

Make	Model	Reg. No	Yr. (Made)	Yr. (Reg)	Engine No.
Eng.(CC)	Eng. Type	Milage			
	2T / 4T				

3.2 Driving information:

Distance Km/day	Hours/ day	Trips/ day	Petrol Liters/day	Petrol Purchased last (liters)	Lube Purchased last (ml)

Interviewer: Make sure that the amounts of petrol purchased and lube oil purchased correspond to the same purchase.

3.3 Lube and fuel quality

	Source	Type		
Lube	Petrol pump / Street vendor	Straight run	2T	Don't Know
Fuel	Petrol pump / Street vendor	Petrol	Octane	Mixture

3.4 Last time serviced (………months prior to clinic):

	Circle appropriate answer	Months prior to clinic
1. Servicing	General cleaning / engine tuning	
2. Spark plug	Cleaned / adjusted / replaced	
3. Silencer	De-carb. / repaired / replaced	
4. Engine de-carbonization	Done / not done	
5. CB point adjustment	Done / not done	
6. Others		

3.5 What condition do you think your baby-taxi is in?

1. Excellent 2. Good 3. Bad 4. Very bad

3.6 Who pays for the maintenance:

Minor 1. Driver 2. Owner

Major 1. Driver 2. Owner

3.7 Vehicle condition (examination report by auto clinic service personnel):

1. Carburetor	Good / tempered / damaged
2. Air Filter	Good/ choked / partly choked / damaged / removed
3. Crank case	Good/ oil leakage / damaged
4. Ignition coil	Good / damaged
5. Ignition cable	Good / damaged
6. Spark plug	Good / worn out / fouled / non-genuine

Part IV Emission Testing Results

Date	
Interviewer	
Vehicle Reg.	

4.1 Emission measurements (initial):

Parameter	Specification	1	2	3	4	5	Average
1. Idle CO (%)	<4.5				xx	xx	
2. Idle HC (ppm)	<10,000				xx	xx	
3. Smoke opacity (%)	<30						

4.2 Initial result: 1. Pass 2. Fail

4.3 First maintenance:

CARBURETOR

	OK	ADJUSTED	COMMENTS
IDLE SCREW			
AIR SCREW			
JET NEEDLE			

SPARK PLUG

	OK	ADJUSTED	COMMENTS
DEPOSIT			
GAP			
COLOR			
HIGH TENSION CABLE			

AIR FILTER

	OK	ADJUSTED/ CLEANED	COMMENTS
FITMENT			
CONDITION			

GENERAL CONDITION

	OK	ADJUSTED	COMMENTS
SILENCER			
OIL LEAKAGE			

4.4 Emission measurements (after first maintenance):

Parameter	Specification	1	2	3	4	5	Average
1. Idle CO (%)	<4.5				xx	xx	
2. Idle HC (ppm)	<10,000				xx	xx	
3. Smoke opacity (%)	<30						

4.5 Result after first maintenance : 1. Pass 2. Fail

(Vehicles failing after first maintenance are sent for a second try)

4.6 Emission measurements (after second maintenance):

Parameter	Specification	1	2	3	4	5	Average
1. Idle CO (%)	<4.5				xx	xx	
2. Idle HC (ppm)	<10,000				xx	xx	
3. Smoke opacity (%)	<30						

4.7 Result after second maintenance : 1. Pass 2. Fail

4.8 Comments / Advice