Cairo Air Improvement Project

Vehicle Emissions Testing Component

Motorcycle Emissions

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Preface

There are approximately 500,000 motorcycles In Egypt, the majority of which feature two-stroke engines. This number is increasing by 5,000 annually, a situation that heavily contributes to air pollution in cities and urban areas such as Greater Cairo, which alone has nearly 170,000 motorcycles.

Motorcycle emissions are significant contributors to air pollution for the following reasons:

- Motorcycles emit high quantities of oils (whether burned or unburned), which may contain harmful compounds due to additives.
- Exhaust emitted from motorcycles contains high quantities of unburned fuel (hydrocarbons), a major contributor to smog formation.

Within the Government of Egypt's efforts to combat motorcycle pollution, the Egyptian Environmental Affairs Agency (EEAA), through the USAID-funded Cairo Air Improvement Project (CAIP), held a workshop on 25/2/1999 to discuss strategies for reducing motorcycle pollution. The workshop's discussions and recommendations highlighted the need to conduct a field study to measure motorcycle pollutants' levels. These levels should be taken into consideration when setting standard emission rates and defining appropriate strategies for tackling the problem.

CAIP consequently conducted a motorcycle on-the-road testing (MORT) program in Greater Cairo during June 1999–December 1999, whereby exhaust emissions of motorcycles were tested. The test sample comprised roughly 2000 motorcycles.

Based on the resulting field study data as well as existing information on how other countries handled motorcycle emissions problems, a number of alternatives were suggested for reducing motorcycle pollution, especially in metropolitan areas.

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Acronyms and Abbreviations

ANOVA	analysis of variance (a statistical analytical method)
CAIP	Cairo Air Improvement Project
cc	cubic centimeters
CO	carbon monoxide
EEAA	The Egyptian Environmental Affairs Agency
ELTRAMCO	The Egyptian Light Transportation Manufacturing Company
g/km	grams per kilometer
HC	hydrocarbons
MORT	motorcycle on-road testing
NOx	nitrogen oxides
ORT	On-Road Testing
PM	particulate matter
ppm	parts per million
QA/QC	quality assurance/quality control
rpm	revolutions per minute
VET	vehicle emissions testing

Vehicle **Executive Summary**

This report contains technical information useful in defining strategies and pertinent policies needed to reduce air pollution resulting from motorcycle emissions.

The report starts with a review of motorcycle emissions, a brief description of motorcycle types, and a comparison between two-stroke and four-stroke motorcycle engines. It then reviews the results of the field study in which motorcycle emissions were measured in Greater Cairo. Finally, the report presents the conclusion and recommendations on the various approaches to mitigate the pollution caused by motorcycles' exhaust emissions.

Below is a summary of the report.

Motorcycles and Air Pollution

Motorcycles are one of the major sources of the following pollutants: particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and other hazardous emissions resulting from the release of burned and unburned lubrication oils.

In terms of PM emissions, a single, two-stroke motorcycle is equivalent to one diesel-powered bus or truck, whereas in terms of HC emission, it is equivalent to 10 gasoline-powered cars. Four-stroke motorcycles, however, emit only slightly more pollutants than gasoline-powered cars.

In Egypt, there are approximately 500,000 motorcycles, of which more than 95% have two-stroke engines. Of this number, 170,000 are in Greater Cairo. Estimates of annual emissions of motorcycles in Greater Cairo are around 700 tons of PM, 16,000 tons of HC, and 15,000 tons of CO.

Field Measurements

HC and CO concentrations were measured for 1,918 motorcycles, of which only 37 are four-stroke motorcycles. Smoke opacity (at garages with large fleets) was measured for 166 two-stroke motorcycles.

As part of the field study, 10 in-use motorcycles were modified through the installation of oil-dosing pumps. Exhaust emissions measurements were taken before and after installation to monitor the effect of metering the oil being mixed with fuel.

Field Measurement Results

Average concentrations of emissions were measured and special statistical tools were applied to deduce from the test results an estimate of average standard rates for motorcycle emissions. The estimate has a high confidence level of 95%.

Average Concentrations of Pollutants in Exhaust Emissions

Average concentrations of pollutants in motorcycle emissions (for the test sample)

Engine type	CO (as %)	HC (in ppm*)	Smoke opacity
Two-stroke	2.56	6064	24.8%
Four-stroke	2.75	742	not applicable

Average concentrations of pollutants in motorcycle emissions (for all motorcycles)

CO	2.49–2.62 %
HC	5820–6150 ppm
Opacity	22.8–26.7 %

Statistical analysis techniques were used to identify the relationships between emissions and a number of motorcycle-related parameters, namely the engine's size and type, number of cylinders, and number of exhaust pipes; and to determine the significance of such parameters on emission levels.

Oil-dosing Pumps

The field study also observed the effect of using an oil-dosing pump in a motorcycle's engine in an effort to reduce pollutants. The following results can be concluded:

- Two-stroke motorcycles that are factory-equipped with oil pumps (40 motorcycles in the study) emitted fewer quantities of pollutants than

* parts per million

regular, two-stroke ones. Estimated reduction is 25% for CO and 29% for HC.

- Upgrading regular two-stroke motorcycles by installing oil-dosing pumps and using oil specifically indicated for two-stroke engines (10 motorcycles in the study) greatly reduces emissions. The sample is too small to be used for drawing reliable quantitative estimates. Such technique, however, has not prevented manual addition of oil, which in some of the case studies had a totally opposite effect as it increased emissions.

Emission Standards

If the standards to be applied are those stated in the Executive Regulations of Environmental Law 4/1994, then the motorcycle compliance rate will be:

Two-stroke motorcycles	6%
Four-stroke motorcycles	84%

To obtain an initial 80% compliance rate, the emission standards should be set as follows:

CO	4%	(Current standards for vehicles: 4.5%–7%)
HC	9000 ppm	(Current standards for vehicles: 900–1000 ppm)
Opacity	40%	(Current standards for vehicles: 50%–60%)

Compliance with such standards would decrease pollutants by the following approximate rates:

CO	30%
HC	30%
PM (opacity)	40%

Conclusion

Based on the scientific facts and field measurements taken, the following can be concluded:

1. It has been shown that emission rates are higher for two-stroke motorcycles than for four-stroke ones. The study emphasizes the pressing need to face this problem, particularly since two-stroke motorcycles make up more than 95% of motorcycles in Egypt.
2. In-use standards can be utilized as a tool to either permit only four-stroke motorcycles or allow both four- and two-stroke ones (applicable to both new and currently in-use motorcycles).

3. There are two alternatives for in-use motorcycles:
   - To permit use of four-stroke motorcycles only, while studying economic and social considerations related to prohibiting two-stroke motorcycles.
   - To permit use of two-stroke motorcycles as well, while studying methods to reduce their emissions to the minimum. It is difficult however to enforce two-stroke motorcycles' compliance with emission standards regardless of whether the standards were high or low, due to technical considerations related to the emission type and emission testing procedures.
4. The reasons for the ineffectiveness of enforcing two-stroke motorcycles to comply with environmental standards are summarized below.
   - **Routine inspection is not useful**. The nature and quantity of oil mixed in the fuel affect measurements. Motorcycle owners could easily adjust these two factors before the motorcycle undergoes inspection thus ensuring success in the emission test regardless of actual compliance of the motorcycle on the road.
   - **Results of emission tests are not reliable**. Noticeable inconsistency of repeated test results occur due to technical characteristics of two-stroke engines' design and operation technique.
   - **Technical difficulties in emission testing procedures**. Such difficulties increase effort, time, and cost. Due to the high concentration of unburned fuel and oil in exhaust, and their resulting precipitation in the test equipment components, false readings may be taken. To avoid false readings, frequent filter replacement is necessary.
     Furthermore, testing motorcycles inside vehicle emissions testing (VET) stations significantly raises the level of indoor pollution, hence requiring either a ventilation system upgrade or the conducting of tests outside the stations.

Consequently, the majority of developed countries do not test emissions for in-use motorcycles. Some countries do not even define in-use standards for motorcycles. The focus instead is on enforcing new motorcycles to comply with defined emission standards before they are introduced into the market.

Suggested Alternatives

The following suggestions present alternatives and their associated procedures to combat air pollution resulting from motorcycle emissions. Suggested solutions deal with both currently in-use as well as new motorcycles.

1. Currently In-use Motorcycles

Reduction of harmful emissions resulting from two-stroke motorcycles which are currently in-use could be achieved through implementing one or more of the options suggested below.

A. <u>Reducing emissions of two-stroke engines</u>

Emissions could be reduced by 25% by using appropriate oils and correct oil/fuel mixture ratios. This could be achieved, with varying levels of success, through:

- Promoting awareness among motorcyclists of the importance of using oils specifically designed for use in two-stroke engines. A suitable method should in this case be provided for controlling the quantity of oil when it is manually added.
- Installing oil-dosing pumps.
- Developing engines by upgrading ignition and fueling systems.
- Encouraging new initiatives such as use of synthetic oils and natural gas.

The first two suggestions aim to reduce emissions by controlling the nature and quantity of oil. It is not expected to get positive results because of motorcycles owners' inclination to raise oil percentage to the maximum in order to extend the engine's life span and avoid engine's failure because of oil shortage. It is to be noted that, currently, oils for two-stroke engines cost nearly twice as much as regular oils.

According to the field study, enforcing any of the above methods appears to be both difficult and ineffective through in-use standards and routine emission inspection. Hence, success of any of these suggestions depends on available implementation subsidy. Because these suggestions are different in terms of their effectiveness in reducing emissions, a techno-economic-environmental study is required to select the best alternative and set the implementation timeframe.

B. <u>Conversion to four-stroke engines</u>

Emissions can be reduced by more than 90% if two-stroke engines are replaced with four-stroke engines in motorcycles. Such a solution can be accomplished by setting emission standards with which <u>only four-stroke engines can comply</u>, and issuing administrative resolutions prohibiting two-stroke motorcycle licensing or usage. Many environmental and economic benefits would ensue, mainly a cutback in operating costs due to reduced fuel and oil consumption.

For this approach to be effective, it is therefore recommended to simultaneously work in several parallel directions, including:

- Make prohibition of two-stroke motorcycles gradual, from crowded areas of major cities, to whole cities exempting open and remote areas.
- Upgrade used motorcycles by installing four-stroke engines in place of two-stroke ones. This has the advantages of being cheaper than new motorcycle purchase and avoiding the problem of discarding old motorcycles. Effective achievement can be ensured through:
  1. Partial or full subsidy for upgrade expenses, with priority given to urban regions. Finance could be through an environmental project in addition to the Social Fund.
  2. Promoting local assembly and/or import of four-stroke engines, by reducing taxes and customs on these engines and their components, at the same time increasing taxes and customs for two-stroke engines and their components.

2. New Motorcycles

It is suggested that emission standards for new motorcycles include the strictest limits for CO and HC emissions in such a way that most four-stroke motorcycles can comply but not two-stroke ones. To implement emission standards for new motorcycles, it is necessary to sign a cooperation agreement between concerned authorities similar to that for new vehicles.

At the same time, in-use standards should be effected as soon as feasible since they would be sufficient to necessitate production/import of four-stroke engines even if they do not include advanced emission control techniques. In-use standards can thus be utilized as a first step to pave the way for necessary arrangements later to enforce emission standards for new motorcycles.

The proposed emission standards for in-use motorcycles are as follows.

CO	2.5%
HC	900 ppm
Opacity	5%

Final Recommendations

1. An integrated plan of action should include the following main tasks:
   - Preparing a comprehensive feasibility study that takes into consideration the technical, economic, and environmental aspects, in order to compare the main alternatives, namely to:
     - A. Continue using two-stroke motorcycles, at the same time implementing the maximum possible emission reduction measures.
     - B. Convert to four-stroke engines, carrying out necessary measures.
   - Inviting concerned parties to participate in selecting the best alternative in view of the techno-economic-environmental feasibility study, and agree on the timeframe for implementing agreed measures.
   - Issuing environmental standards for new and in-use motorcycles in view of feasibility study results, which will be used to determine whether or not two-stroke motorcycles will be allowed to comply as well. Dates of enforcement of standards will be defined according to the timeframe agreed by concerned parties.
2. Since there are economic and social factors to be considered with respect to the motorcycle emissions issue, a preliminary meeting is recommended, to be attended by representatives of concerned parties, namely the Federation of Egyptian Industries, Association of Chambers of Commerce, and the Ministries of Petroleum, Interior, Industry, Economy, and Foreign Trade. The meeting's aim is to present results of this report and suggested mitigation plan, and highlight the importance of cooperation and input from these parties to supply required information for feasibility study preparation.

Introduction
Motorcycles and Air Pollution

Motorcycles represent a rapid means of transportation because they are smaller and lighter than other vehicles. Statistics show diversity in the ratio of motorcycles to vehicles in different countries. Among the countries where motorcycles form a low percentage are Portugal (2.9%), the United Kingdom (3.6%), the United States (3.7%), Chile (3.9%), Canada (7%), and Germany (7.3%)

On the other hand, motorcycles in the following countries form a relatively high percentage of all transportation means: many Asian countries such as Indonesia (74.6%), Taiwan (73.4%), India (69.6%), Thailand (66.1%) and Malaysia (59%); and other countries such as Venezuela (25.3%), Italy (23.8%), Switzerland (20.7%) and Austria (14.9%). Egypt's 500,000 motorcycles represent 18% of the total number of vehicles.

There is also diversity in the purposes for which motorcycles are used. In USA and Europe, motorcycles are used for exercising, fun and riding in open areas, whereas in some Asian countries, motorcycles are heavily used as a transportation means for both individuals and goods in overcrowded areas. In the latter situation, the impact of motorcycles on the environment and especially on air pollution is magnified. This is the situation in Greater Cairo, Egypt, whose some 170,000 motorcycles are mostly used for transportation of individuals and goods.

Pollutants of Motorcycle Emissions

As motorcycles use gasoline, the composition of their exhaust emissions is similar to that of gasoline-operated vehicle emissions. Mainly, emissions contain carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter (PM).

However, the quantity and quality of motorcycle emissions vary according to the engine's design and capacity, which ranges from less than 50 cubic centimeters (cc) to more than 700 cc. The most commonly used types in Egypt do not exceed

350 cc in capacity. The bigger the engine's capacity, the more the exhaust emitted in quantity but not concentration, which contrarily increases in smaller engines.

In terms of the design of motorcycle engines, there are two types: *two-stroke* and *four-stroke* engines. There are fundamental differences between them in the theory of operation and in composition, hence a difference in the quality of emissions.

In general, four-stroke motorcycle emissions are nearly equivalent to emissions of small cars, since car engines are typically four-stroke engines. However, emissions of two-stroke motorcycles have larger quantities of unburned HC and PM (smoke). Studies and measurements in many countries including the USA and some Asian countries indicate that PM emissions from a single two-stroke motorcycle equals the emissions of a heavy truck or a diesel bus, and HC emissions equals those of 10 gasoline cars. Yet, in terms of CO emissions, there is no significant difference between two- and four-stroke engines.

The basic differences between two- and four-stroke engines are further explained in various sections of this report.

Two-stroke and Four-stroke Engines

Both two- and four-stroke engines can be used to generate the energy to move motorcycles. As mentioned earlier, there are fundamental differences between them, including the method of adding the fuel/oil mixture, emissions discharge, and the method of oil lubricating engine parts.

A four-stroke engine has the advantages of being equipped with mechanical valves to control fuel inlet and emissions exit, and a closed lubricating system. In addition, four-stroke engines are commonly used in other vehicles. Two-stroke engines have a different system of fuel/oil mixture charging and emissions discharging which enables emission of high quantities of air/unburned fuel mixture. Oil lubrication is done through adding extra oil to the fuel to lubricate engine parts, which naturally causes emitted exhaust to contain a portion of the oil, unburned just like fuel/air mixture.

Particulate matter emitted in motorcycle exhaust is especially hazardous as it includes particles of oil and byproducts of its burning which could include toxic substances coming from oil additives.

When comparing the technical characteristics of two- and four-stroke engines of equal capacities, we can conclude that the two-stroke engine is smaller and lighter, and is therefore more powerful in terms of speed and acceleration. This is why two-stroke motorcycles are more popular. It is not only their powerfulness that appeals to people but also their low prices as a result of low manufacturing costs. It is to be noted though that their operating costs in terms of oil and fuel consumption are higher than four-stroke motorcycles of similar capacities.

Chapter One
The MORT Program

The approach chosen to test motorcycle emissions was through the On-Road Testing (ORT) program for vehicles, in order to utilize readily available resources in terms of the equipment and experience in the field of emissions testing. A significant advantage of this approach is that it cuts through red tape, since ORT is a convenient umbrella through which stopping motorcycles to take readings is feasible. The extension of the ORT program to test motorcycles was coined MORT, for *Motorcycle On-Road Testing* program.

1-1 MORT Objectives

The program aims to measure emissions of a sample of motorcycles as a preparatory step for setting appropriate standards and policies to reduce emission pollutants. An additional important aim is to raise people's awareness of the harmful effects of motorcycle emissions and how to minimize them.

1-2 Program Scope

MORT program scope comprises three basic activities:

- Measuring HC and CO for 1,918 motorcycles
- Measuring opacity for 166 motorcycles
- Installing oil-dosing pumps for 10 motorcycles and measuring emissions before and after modification

Measuring CO and HC

The concentrations of CO and unburned HC in exhaust emissions were measured during the period July 1999–October 1999.

Measurement devices were located at a number of highway entrances, and attended by the inspectors trained to perform MORT. The highways selected are those characterized by particularly heavy motorcycle traffic, namely: the Cairo–Alexandria Agricultural Road, Cairo–Ismailia Desert Road, and Cairo–El-Fayoum Desert Road.

Additionally, a number of measurement devices were placed at traffic units where a lot of motorcycles are registered. The selected units are Shoubra El-Kheima Traffic Department, Shoubra (Abboud) Traffic Department, El-Darrasa Traffic Department, and El-Hawamdiya Traffic Department.

Measuring Opacity

The opacity test was conducted at sites with large motorcycle fleets, in garages of the Ministry of Agriculture and Al Ahram Organization (issuing Al Ahram newspaper). The intention was to collect the largest amount of data in the shortest time. Smoke opacity test was conducted for 166 motorcycles.

Installing Oil-dosing Pumps

Included in the field program was also a study of the effect of installing oil-dosing pumps to replace manual addition of oil. The study included testing CO, HC and smoke opacity before and after installing oil dosing pumps in 10 motorcycles, of which 7 belong to the Agricultural Research Center and 3 to Al Ahram Organization.

Figure 1–1 illustrates the test sites, Figure 1–2 the number of motorcycles tested throughout the program duration, and Figure 1–3 the number of motorcycles tested at each site.

Figure 1-1

Figure 1.2
Motorcycles Tested by Month of Program

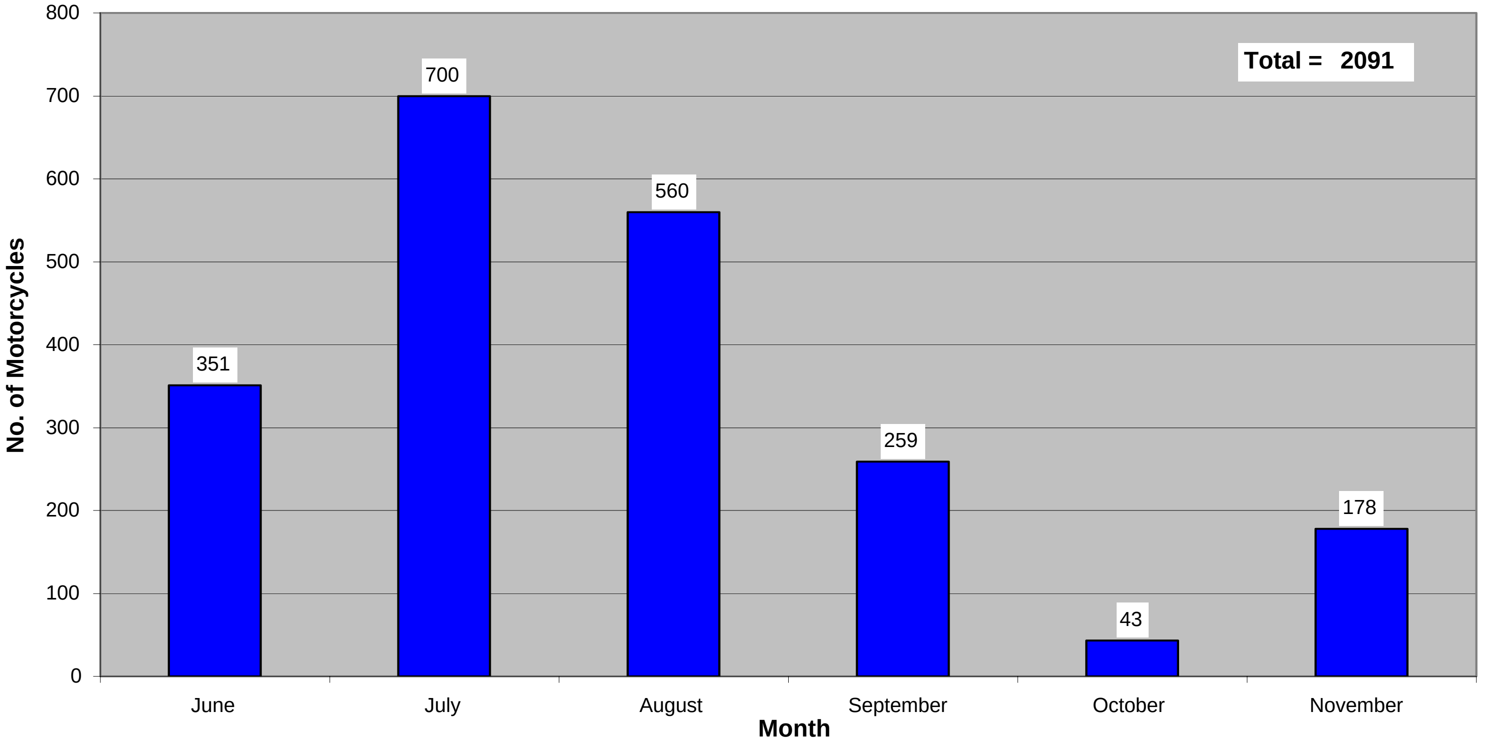
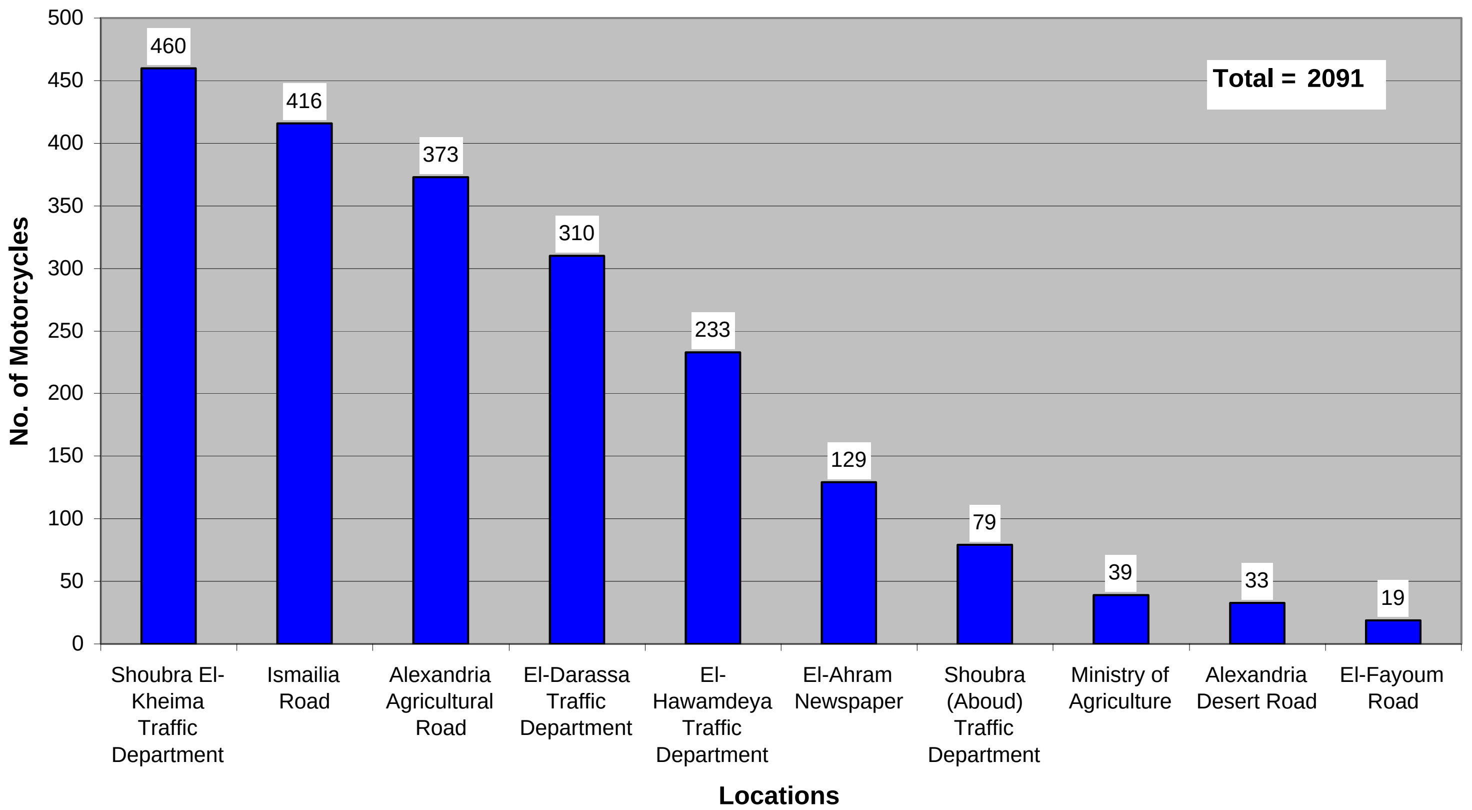


Figure 1.3
Motorcycles Tested by Location



1-3 Emissions Testing Methods

Concentrations of HC and CO pollutants were measured at idle (slow) speed of the engine, as is the common practice in measuring pollutants emitted from gasoline engines. It is also one of the measurement conditions defined in Article No. 37 of the Executive Regulations of Law 4/1994.

Smoke opacity was measured at maximum acceleration in accordance with Article No. 37 of the Executive Regulations of Law 4/1994. As stated in the US standards specifications (SAE 1667) smoke opacity was measured three times and their average value recorded as the final measurement.

1-4 Measurement Equipment

The program measured the concentration of what is considered the major pollutants in motorcycle emissions, namely CO, HC, and smoke opacity. Emission analyzers are typically used to measure HC and CO, whereas smoke opacity measurement requires other types of equipment. Below is an overview of the equipment that was in the program.

HC and CO Measurement Equipment

Motorcycle emissions are characterized by a higher concentration of unburned HC than emissions of other ordinary vehicles. Therefore, wide-range testing equipment (20,000 ppm) should be used. Furthermore, due to the presence of large quantities of unburned oils in motorcycle emissions, testing equipment becomes quite dirty thus requiring special maintenance procedures and more frequent filter replacement. As a result, emission analyzers with a measurement range not exceeding 10,000 ppm cannot be used in conjunction with many motorcycles.

Consequently, information was collected on available measurement equipment whose measurement range for HC reaches up to 20,000 ppm. Manufacturers were then contacted to check the equipment's suitability for measuring motorcycle emissions, and to find out the additional maintenance procedures needed to guarantee accuracy of measurement. Seven SUN MGA 1200 emission-testing devices were selected, the model recommended by the manufacturer as the most suitable to use with motorcycles. This was included in the quality assurance and quality control (QA/QC) procedures for the testing results.

Smoke Opacity Measurement Equipment

Smoke opacity measurement needs special equipment due to the presence of large quantities of unburned oils in motorcycle emissions. Three WAGER 6500 opacity measurement devices, owned by Shoubra El Kheima Station, were used. The devices were not procured till the last phase of the field study, and it was thus possible to test opacity in 166 motorcycles only.

1-5 Collected Data

The form shown in Figure 1–4 was designed for collection of data on tested motorcycles. The data was then entered onto a database designed specifically for this purpose (See Appendix). Data required by the form includes motorcycle data as per its license and information about the method of usage, type of oil used, and ratio of oil added to gasoline.

The form also includes a section to record results of HC and CO measurement in emissions at idle speed. A section was added for smoke opacity percentage (%) at maximum acceleration, as specified in standards of smoke opacity tests. For motorcycles with two tailpipes, test results were recorded for each separately.

1-6 QA/QC Procedures

Several QA/QC procedures were applied on collected data to achieve a sufficient degree of accuracy of the study results throughout its phases, including training of EEAA Inspectors on measuring equipment usage, equipment maintenance and adjustment, data collection, and data entry and analysis.

Training of Inspectors

The MORT Program was implemented with the assistance of seven EEAA inspectors who were given special training to conduct MORT. The training covered main theoretical aspects and included hands-on training. Selection of Inspectors was based on an overall evaluation of their efficiency, during ORT, in using emission equipment and their experience in dealing with the public.

Figure 1 - 4

General Traffic Department **Egyptian Environmental Affairs Agency**

Serial No. ____________

Motorcycle Emissions Inspection Form

General Information	
Inspection Site	Motorcycle Plate Number
License Issuance	Number of Cylinders
Motorcycle Make	Manufacture Year

Inspection Results				
Emission Type	Results for 1st exhaust pipe	Results for 2nd exhaust pipe (if available)	No. of Strokes	
			Type of Oil	
Hydrocarbons			Percentage of oil to fuel in mixture	
Carbon monoxide			Revolutions per minute (RPM)	

EEAA Engineer
Name:
Date:

Maintenance and Calibration of Testing Equipment

Maintenance and calibration of the seven SUN MGA 1200's selected for measuring CO and HC concentrations was conducted in accordance with the manufacturer's instructions. Required maintenance included routine replacement of filters according to the number of tests conducted as well as the routine overall inspection that maintains optimal equipment performance hence ensures the validity of testing process and accuracy of results.

The three WAGER 6500's used for opacity measurement were characterized by being modern and easy to use, having simple maintenance and calibration procedures, and nevertheless providing accurate results.

Data Collection and Computerization

A system was established for collecting data forms on a weekly basis from testing locations, by the program's EEAA coordinators, then handing over the forms to CAIP for initial review before having data entered onto the computerized database system designed for the MORT program.

Data Review and Error Detection

The computerized database was designed such that data entry mistakes are minimized. Further data checking included reviewing data entered against the data collection forms for a random selection comprising 300 motorcycles.

Test Sample Size and Accuracy of Deductions

Despite the large number of motorcycles in Egypt, no information on their emissions was available. Given this lack of base information, it was necessary to conduct the study with the aim of collecting as much information as possible in the shortest time. Accordingly, 2091 motorcycles were tested in Greater Cairo (which has some 170,000 motorcycles in total). Although the test sample size is small compared to the total number of motorcycles, it is adequate for deducing general indicators on emission levels with an acceptable degree of accuracy.

More specific indicators that could be deduced are less accurate. When the sample is subdivided into categories according to motorcycles' make or model year, accuracy decreases as the category gets smaller. For example, the test sample contained a limited number, 37, of four-stroke motorcycles, which implies lower accuracy of conclusions related to four-stroke motorcycles as compared to two-stroke motorcycles. Similarly, smoke opacity results from the 166-motorcycle sample give less accurate conclusions than CO and HC measurements taken from some 1,918 motorcycles.

Data on oil types and ratio of oil added to fuel were taken. However, when this data was reviewed it was found to be invalid for analysis because most motorists did not know precisely the actual ratio of oil to fuel, which is also difficult to control.

Chapter Two
Field Study Results

Motorcycle emissions testing was carried out in three phases:

- **Measuring CO and HC concentrations**: 1,918 motorcycles were tested
- **Measuring smoke opacity**: 166 motorcycles were tested.
- **Evaluating the use of oil-dosing pumps**: oil-dosing pumps were installed in 10 motorcycles, CO and HC concentrations were measured before and after the installation of pumps. As for opacity, only 9 motorcycles were tested since one motorcycle could not be tested for reasons associated with usage conditions.

2-1 Characteristics of the Test Sample

To define the characteristics of the test sample and describe them in the form of statistics and graphs, the database of field results was used to categorize motorcycles according to model year and make.

Model Year

Figure 2–1 shows the distribution of tested motorcycles according to model year. The cumulative curve displays that approximately 10% of tested motorcycles are pre-1976 models, and more than 50% are 1976 and later models.

Figure 2.1
Motorcycles Tested by Model Year

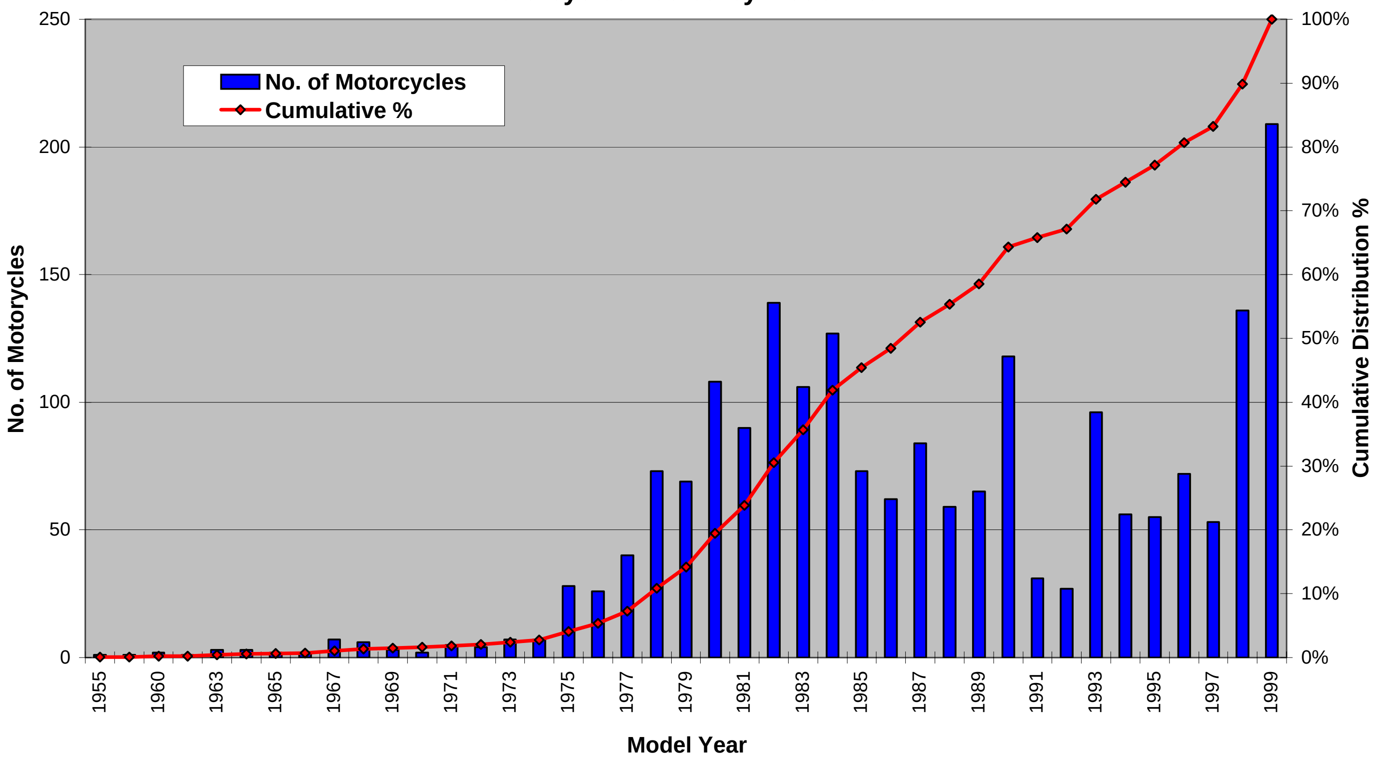
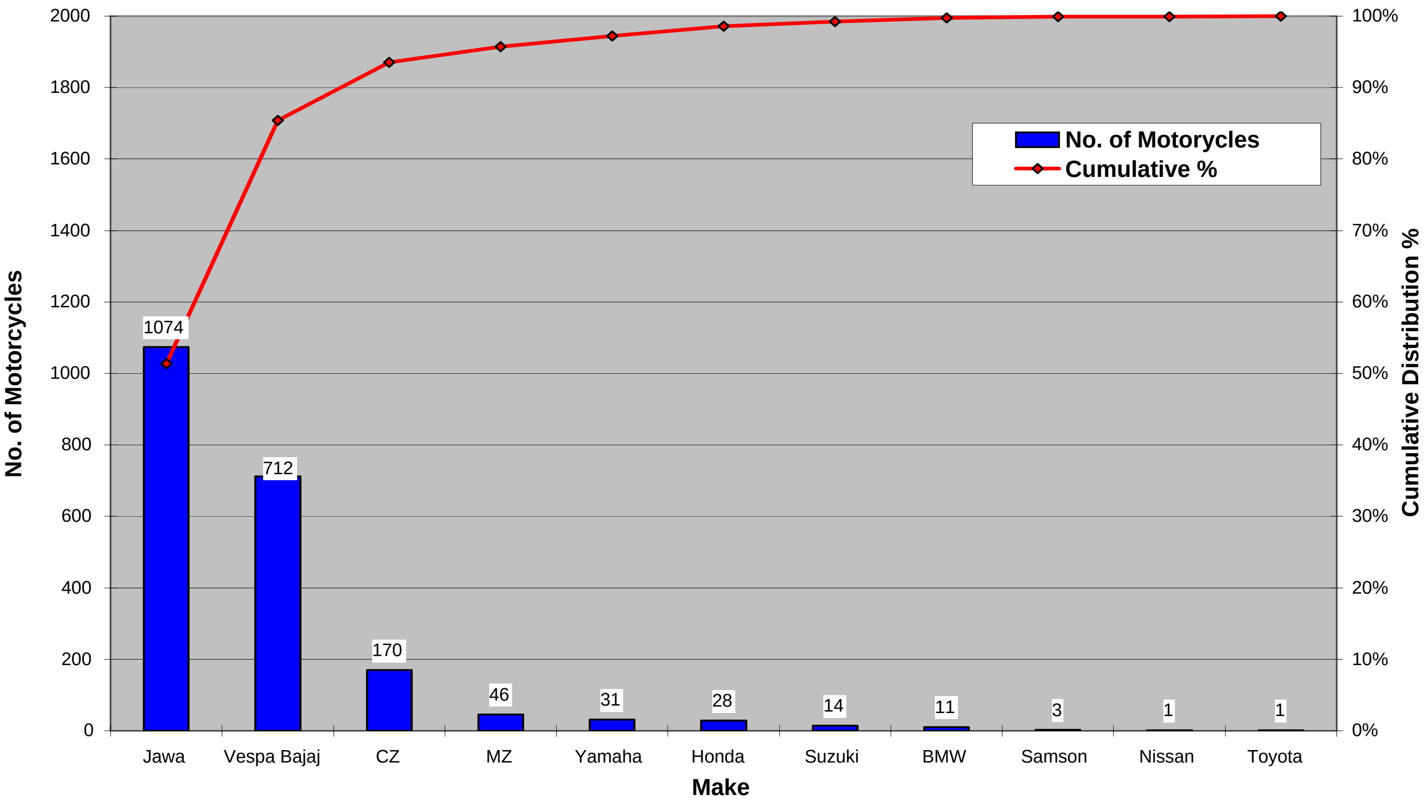


Figure 2.2
Motorcycles Tested by Make



Motorcycle Make

Figure 2–2 shows the distribution of tested motorcycles according to their make. The table below summarizes the major motorcycle makes and their proportions in the test sample.

Motorcycle Make	Number of motorcycles	Percentage (%)
Jawa	1072	51
CZ 175	712	34
Vespa	170	8
Other makes	137	7
Total	**2091**	**100**

Number of Cylinders

An engine's power and capacity are generally related to the number of cylinders it has. Motorcycle engines may have one, two, or four cylinders. Figure 3–2 illustrates the distribution of tested motorcycles according to the number of cylinders. A summary is presented in the table below.

No. of Cylinders	No. of Motorcycles	Percentage (%)
One	982	47
Two	1086	52
Four	23	1
Total	**2091**	**100**

Number of Tailpipes

Measurement method and results depend on whether the tested motorcycles are equipped with one or two tailpipes. The table below shows the distribution of tested motorcycles according to the number of tailpipes.

No. of Tailpipes	No. of Motorcycles	Percentage (%)
One	1194	57
Two	897	43
Total	**2091**	**100**

Figure 2.3
Motorcycles Tested by No. of Cylinders

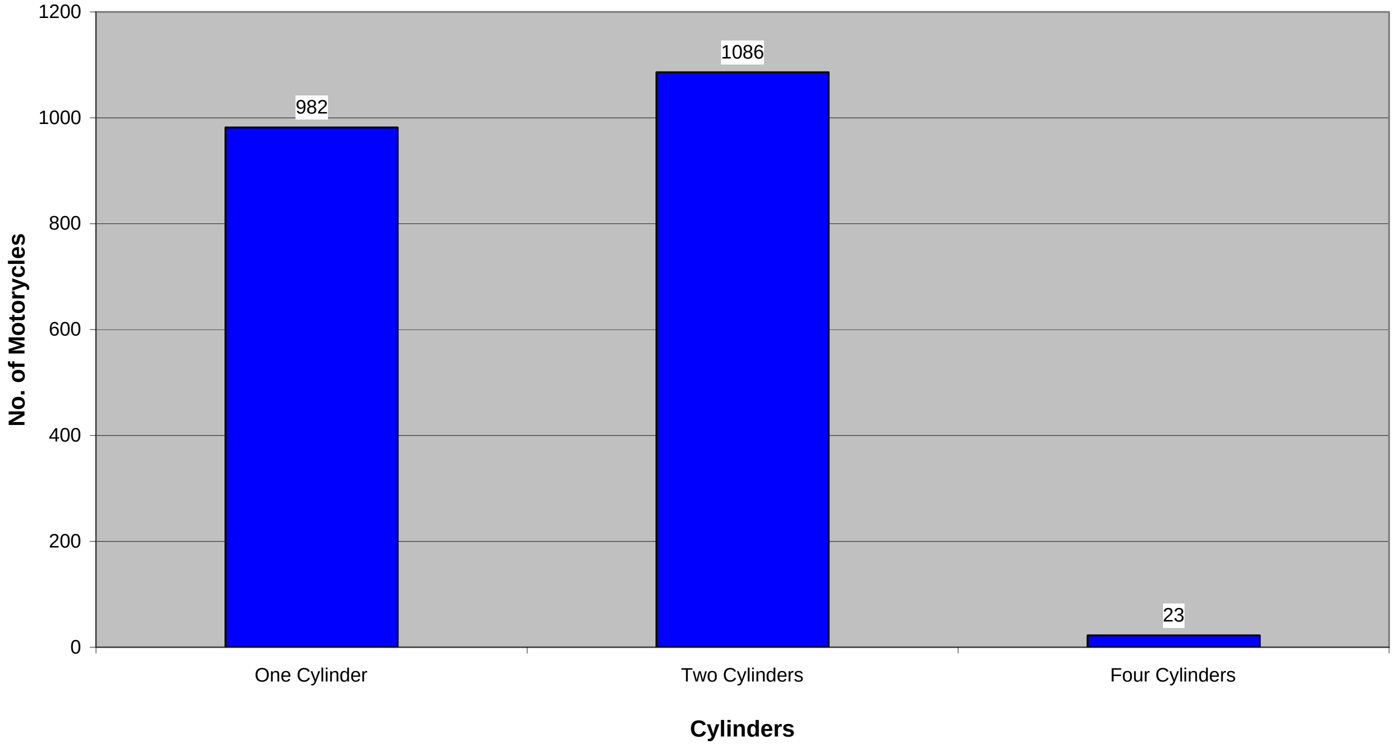
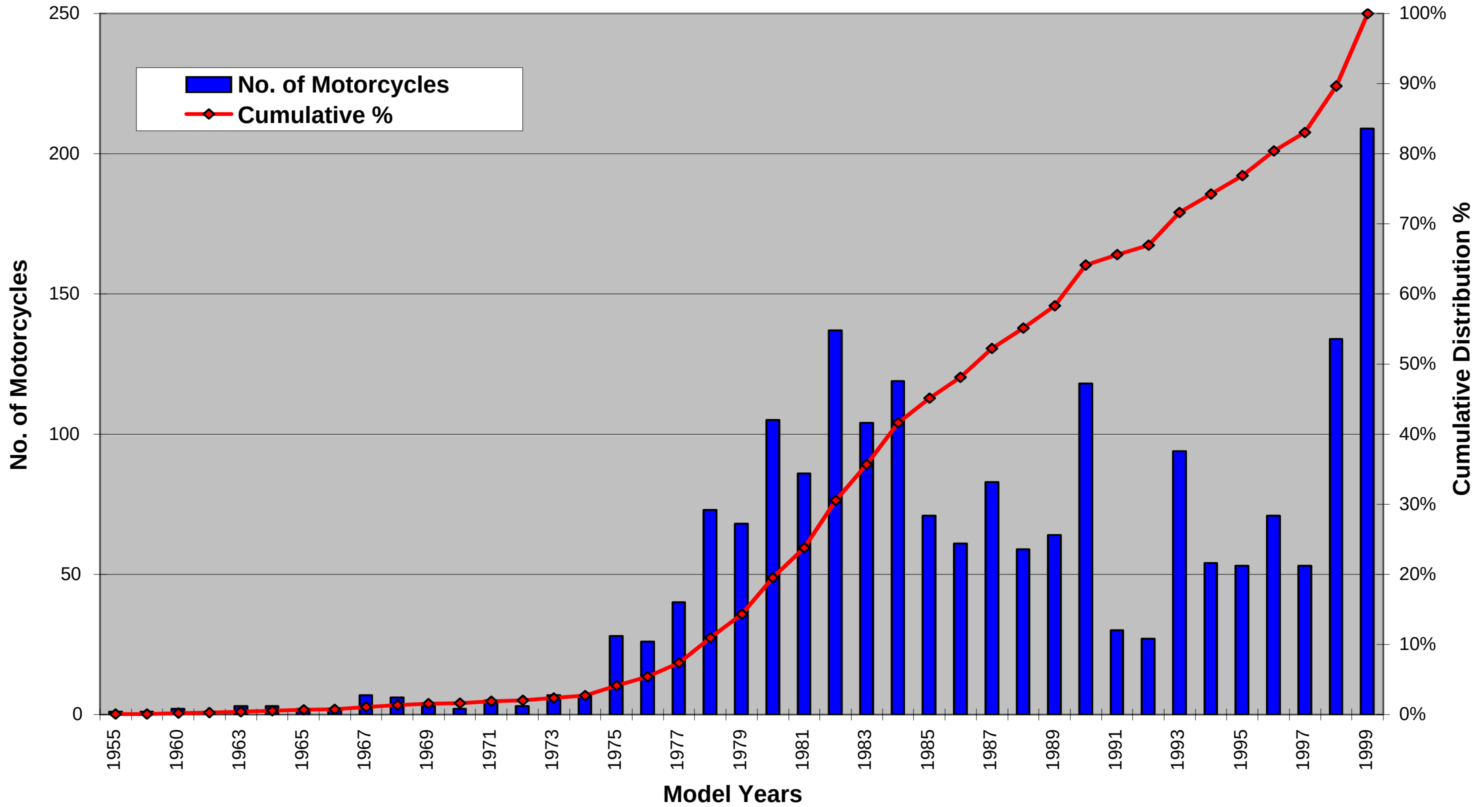


Figure 2.4
Two Stroke Motorcycles Tested by Model Year



Engine Type

A significant factor determining the concentration of pollutants in exhaust emissions is the engine type, which in motorcycles may be two-stroke or four-stroke. Two-stroke engines have higher rates of HC emissions and opacity levels. The table below shows the distribution of tested motorcycles according to the engine type:

Engine Type	Number of motorcycles	Percentage (%)
Two Stroke	2054	98
Four Stroke	37	2
Total	**2091**	**100**

It is worth noting that two-stroke motorcycles represent 98% of the sample, which is a rough indicator of the actual rate of two-stroke motorcycle usage in Greater Cairo.

Figures 2–4 and 2–5 illustrate the classification of two-stroke motorcycles according to their model year and make respectively. Figures 2–6 and 2–7 illustrate the same classifications but for four-stroke motorcycles.

Figure 2.5
Two Stroke Motorcycles Tested by Make

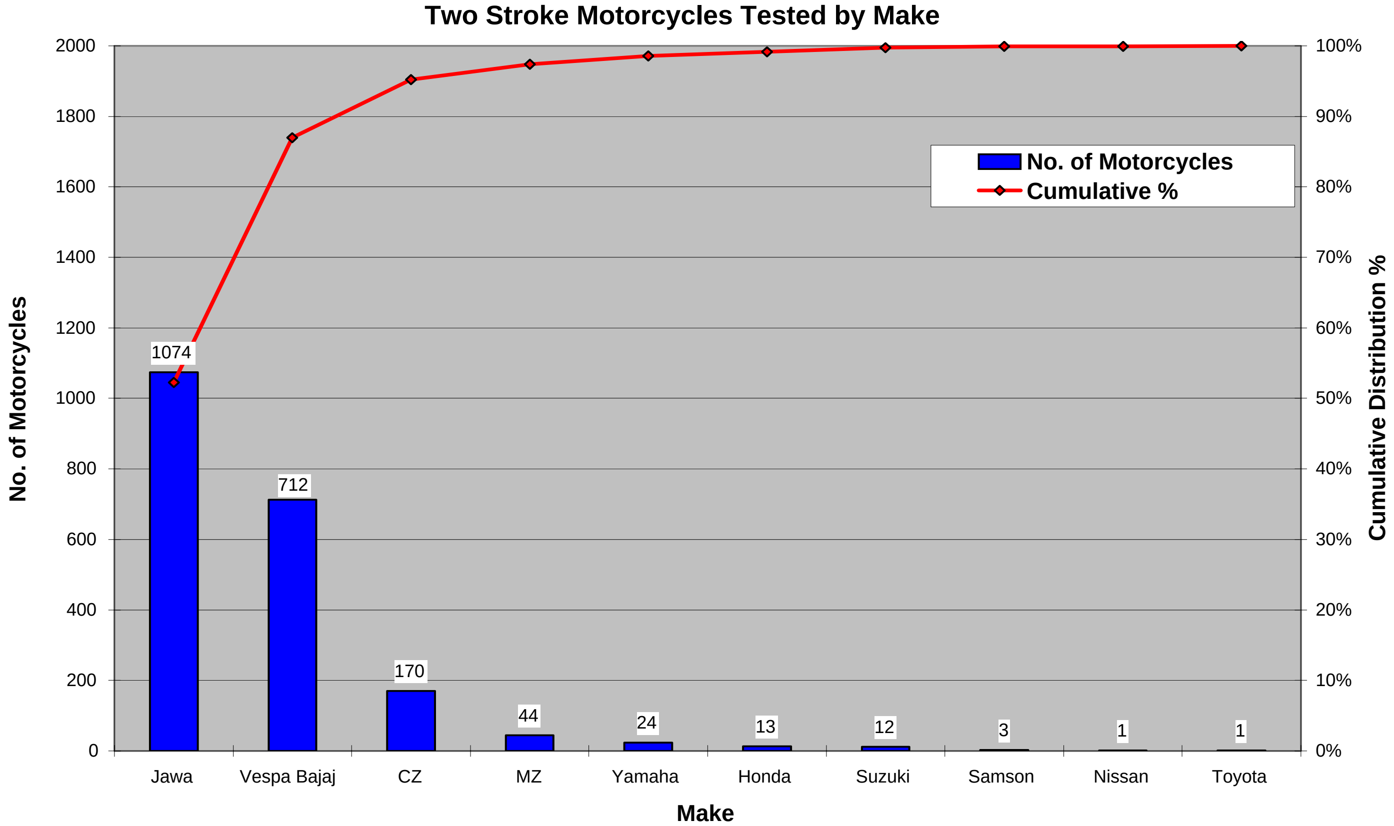


Figure 2.6
Four Stroke Motorcycles Tested by Model Year

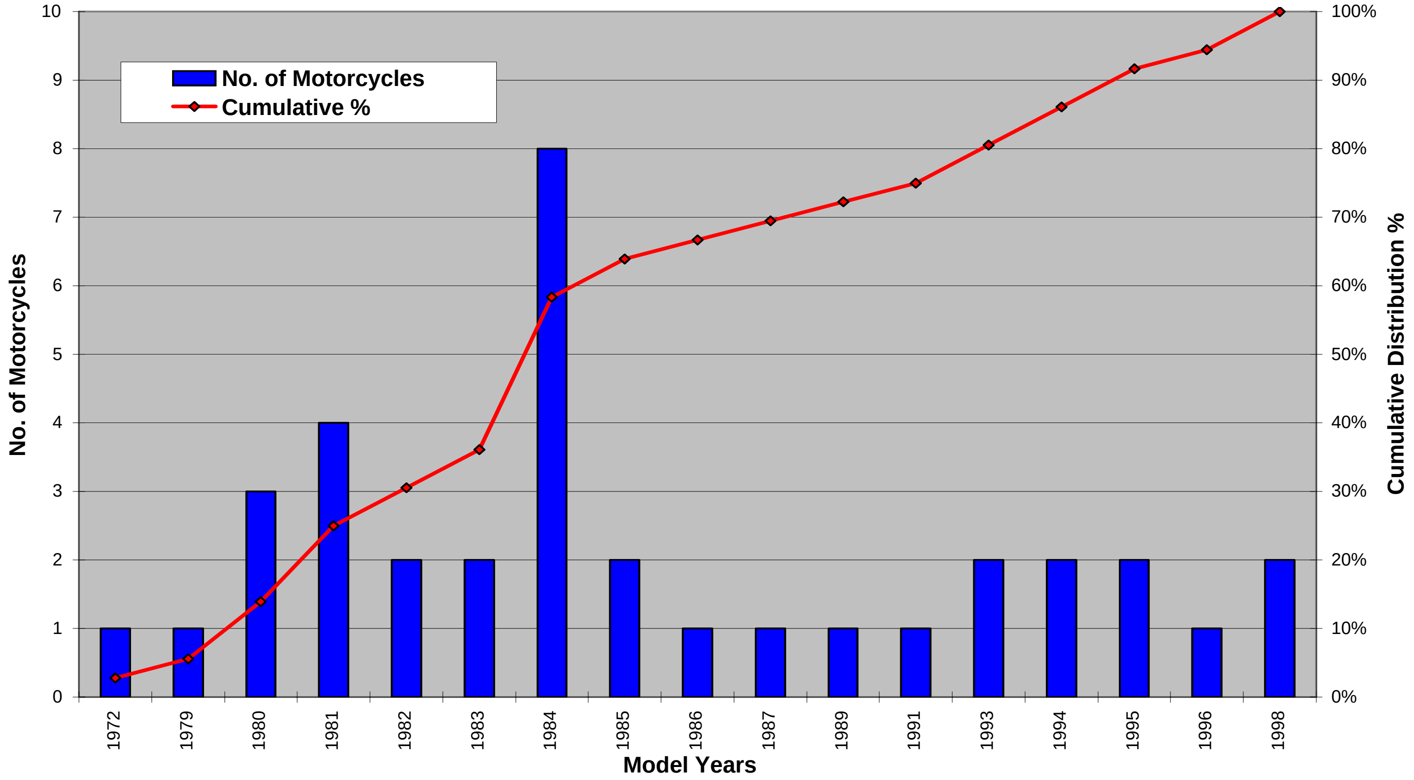
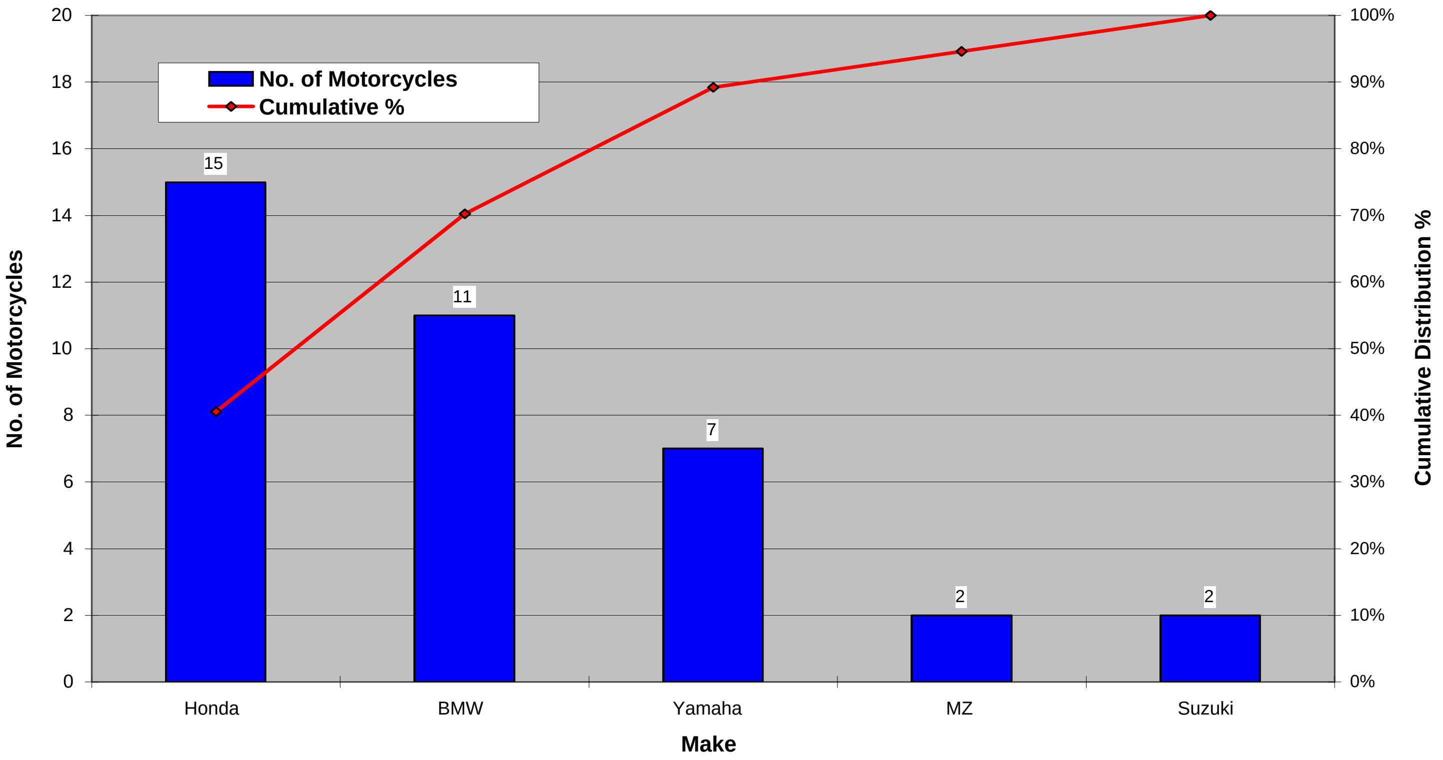


Figure 2.7
Four Stroke Motorcycles Tested by Make



2-2 Emission Levels

Statistical analysis techniques were utilized to compute pollutant levels in motorcycle emissions from the tested sample. From the sample data, expected limits of emissions in general were estimated using statistical relations (with a 95% confidence level).

Data was processed at different levels of detail, as follows:

- The entire sample as one unit representing motorcycles in Greater Cairo to formulate a general picture of motorcycle emission levels.
- The sample divided into two groups according to the engine type (two- & four-stroke) to define the characteristics of each group independently.

For motorcycles equipped with 2 tailpipes, each tailpipe was considered an individual emission source when estimating the averages of emissions. But when measuring compliance rates with specified standards, the 2 tailpipes were considered a single emission source and the average of their data was recorded as a single reading.

The next sections demonstrate the results of measurements taken in the field study, namely data related to HC and CO emissions based on measurements of 1,918 motorcycles, results of opacity measurements in 166 motorcycles, and the results of installing oil-dosing pumps for 10 motorcycles. In all cases, the data items considered were the ones that passed QA/QC procedures.

2-2-1 Overall Motorcycle Results

This section describes the results of the field study considered for the entire sample comprising the total number of motorcycles measured.

Carbon monoxide

Figure 2–8 illustrates the number of motorcycles according to CO emission levels (as percentage), taking each tailpipe as an individual source of emissions. The graph shows that nearly 90% of motorcycles emit less than 4% of CO. The statistical analysis indicates the average concentration of CO in the test sample to be 2.56%, while the general average of CO emissions in motorcycles ranges from 2.49%–2.62% with a 95% confidence level.

Figure 2.8
Carbon Monoxide (CO) Data for Tailpipes as Individual Sources

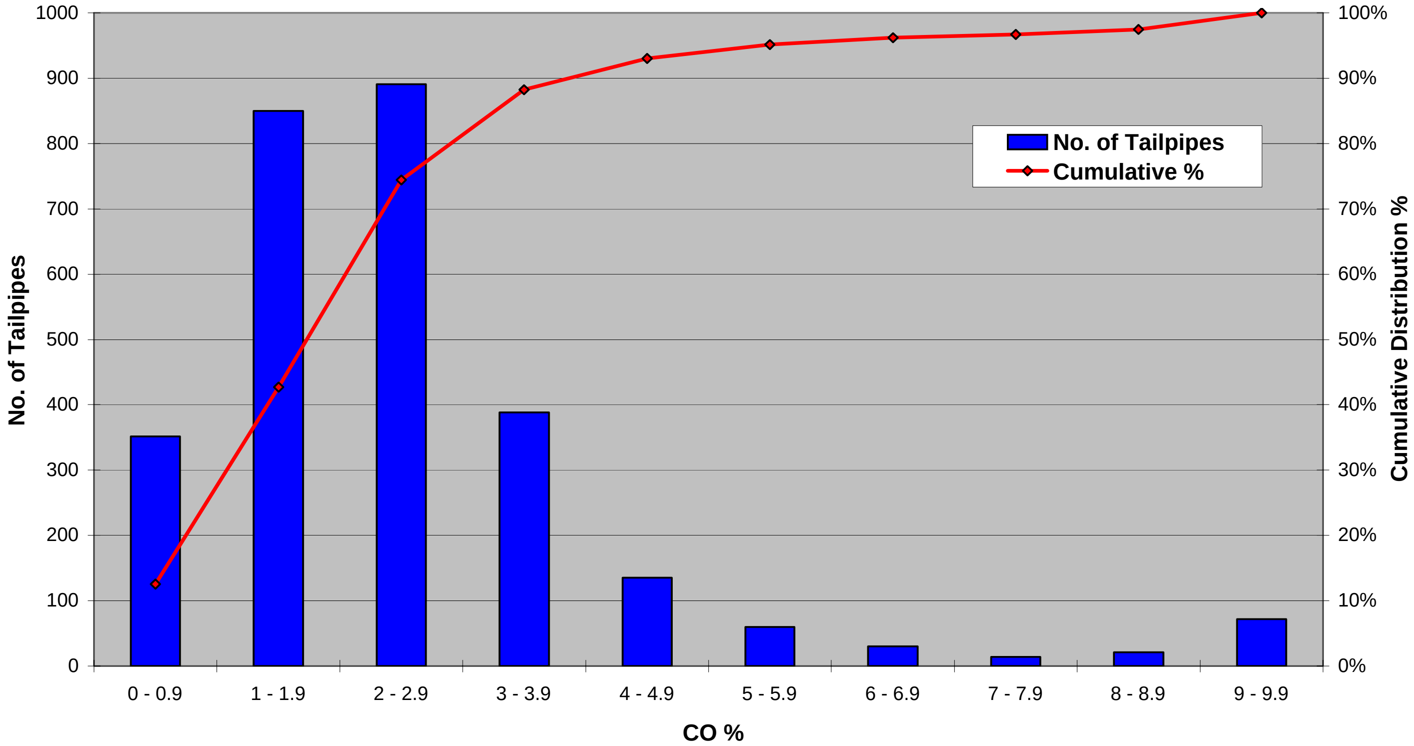
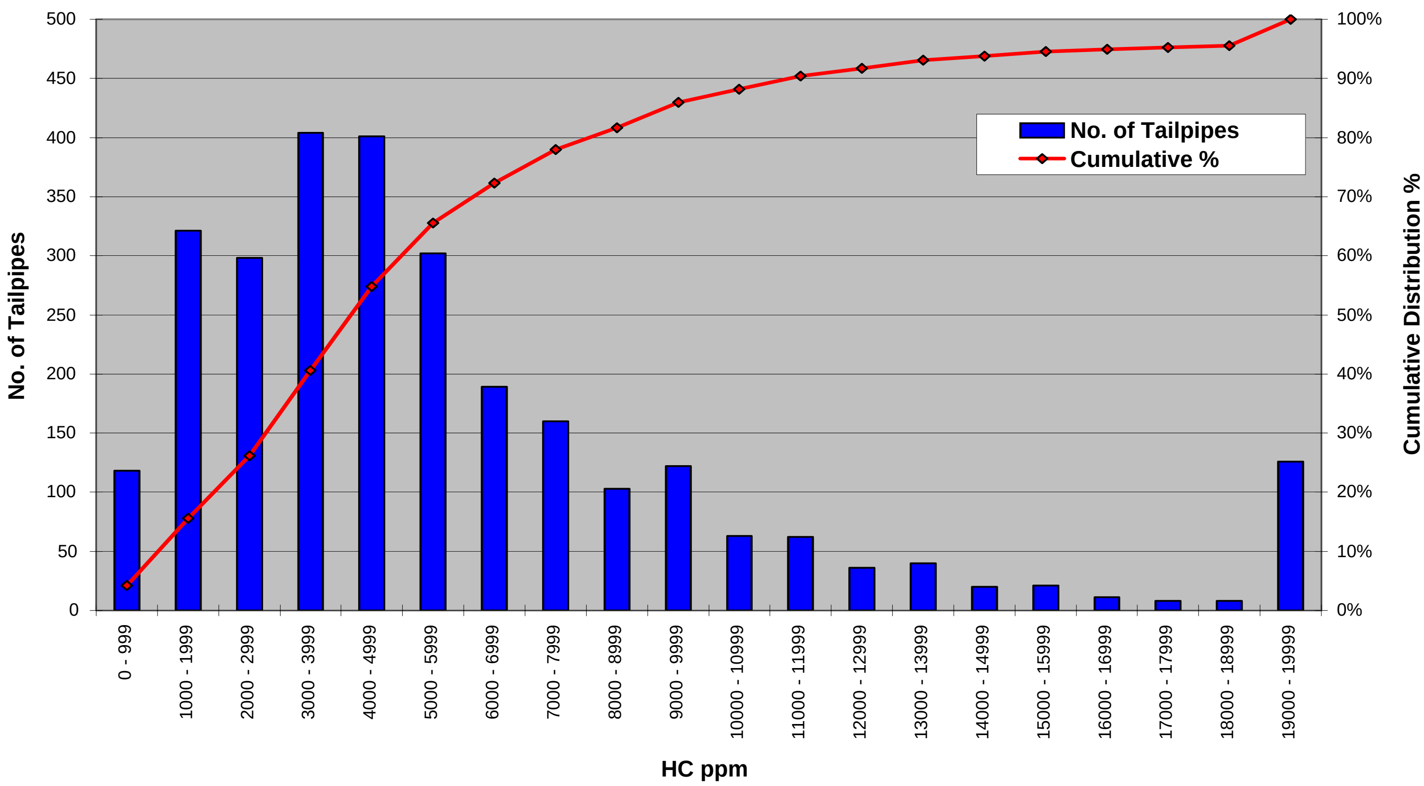


Figure 2.9
Hydrocarbons (HC) Data for Tailpipes as Individual Sources



Hydrocarbons

Figure 2–9 illustrates the number of motorcycles according to the average concentration of HC in exhaust. The graph shows that approximately 85% of motorcycles have HC emission concentrations in the range 1,000–10,000 ppm, and 15% have HC emission concentrations in the range 10,000–20,000 ppm. The average HC concentration in the test sample is 6,064 ppm, while the general average is in the range 5820–6150 ppm, with a 95% confidence level.

Smoke opacity

Smoke opacity was tested for 166 motorcycles at maximum acceleration in accordance with common practice for measuring opacity of diesel engines.

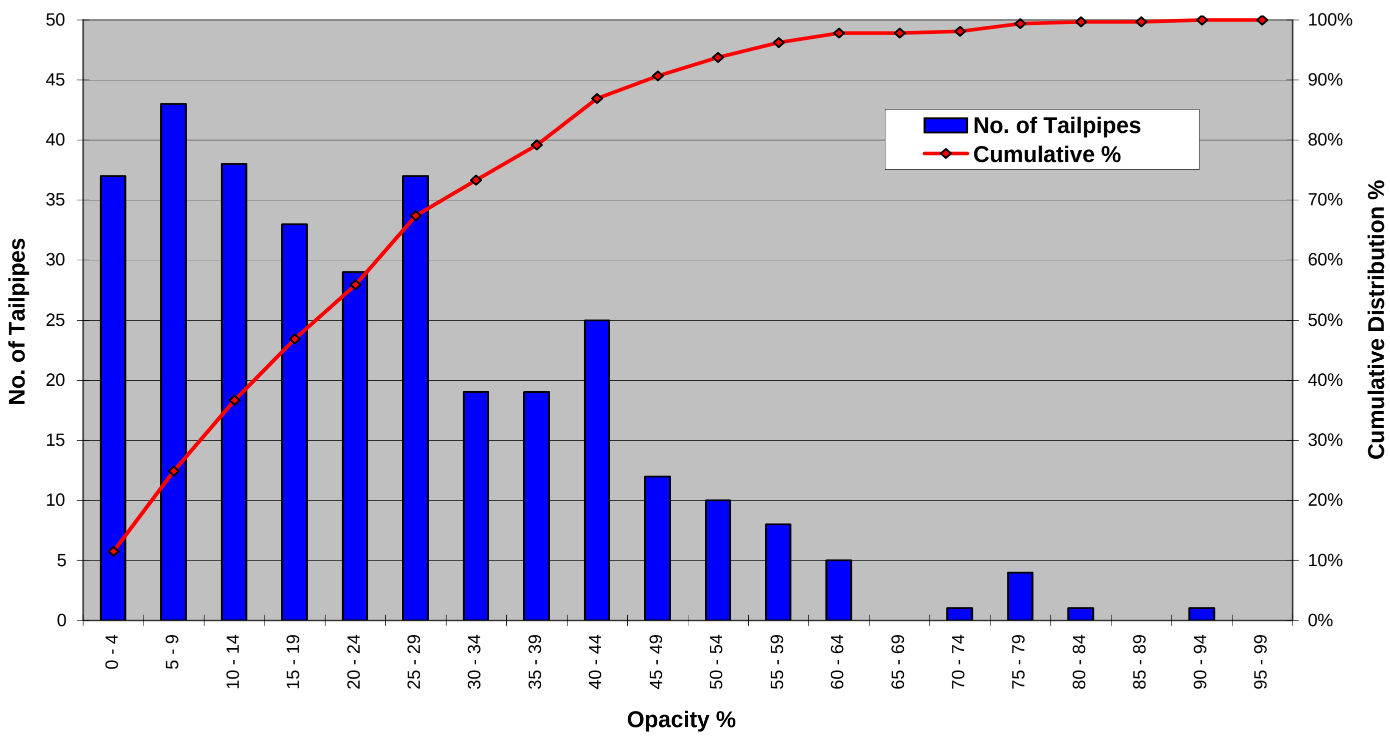
Figure 2-10 shows that smoke opacity is less than 40% in approximately 80% of the test sample, and less than 50% in 90% of the sample.

Statistical analysis indicates that the average of smoke opacity in the test sample is 24.8%, while the general average of opacity ranges between 22.8%–26.7% with a 95% confidence level.

It is important to mention that opacity tests were conducted for two-stroke motorcycles only, as there were no four-stroke motorcycles available at the two garages where opacity was tested.

Figure 2.10

Opacity at Maximum Speed Data for Tailpipes as Individual Sources



2-2-2 Comparison between Two-Stroke and Four-Stroke Engines

The breakup of tested motorcycles based on engine type is 2054 two-stroke motorcycles and 37 four-stroke motorcycles. Although the number of two-stroke motorcycles is much larger than the number of four-stroke motorcycles, yet apparent differences can be deduced from measurements. The analytical method, Analysis of Variance (ANOVA), was used to verify the significance of the differences with a 95% confidence level.

Carbon monoxide

Figure 2–11 illustrates the cumulative distributions for two- and four-stroke motorcycles (Figure 2-11 A & Figure 2-11 B respectively) for the average concentration of CO in emissions. It can be seen that the statistical distribution of motorcycles is the same for both types of engines, taking into consideration the difference in numbers. In both cases, the concentration of CO is less than 4% in more than 85% of the cases. The average concentration of CO is 2.56% for two-stroke motorcycles and 2.68% for four-stroke motorcycles. Statistical analysis indicates that the difference is insignificant.

Unburned hydrocarbons

Test results shown in Figures 2–12 A and B indicate that most two-stroke motorcycles (approximately 60%) have HC emissions in the range 1000–6000 ppm, while the concentration of HC in four-stroke motorcycles does not exceed 2000 ppm in most cases. The calculated general average concentration of HC is 6064 ppm in two-stroke motorcycles, but only 742 ppm in four-stroke motorcycles. This implies that HC emissions of two-stroke motorcycles are nearly 8 times those of four-stroke motorcycles.

Smoke opacity

As mentioned above, opacity was measured for two-stroke motorcycles. The average opacity for the test sample was 24.8%, while the general average of opacity is in the range 22.8–26.7%. This deceptively apparent low opacity level is a result of the presence of unburned oils in motorcycle emissions, which are relatively light in color thus lowering the reading of the opacity measurement equipment, which depends in taking the reading on the degree of "blackness" of the exhaust.

As for four-stroke motorcycles, it is known that opacity is not significant in their case. There is no need therefore to test smoke opacity for four-stroke motorcycles, which is the case for gasoline-powered vehicles.

Figure 2.11 - A
Two Stroke CO Data for Tailpipes as Individual Sources

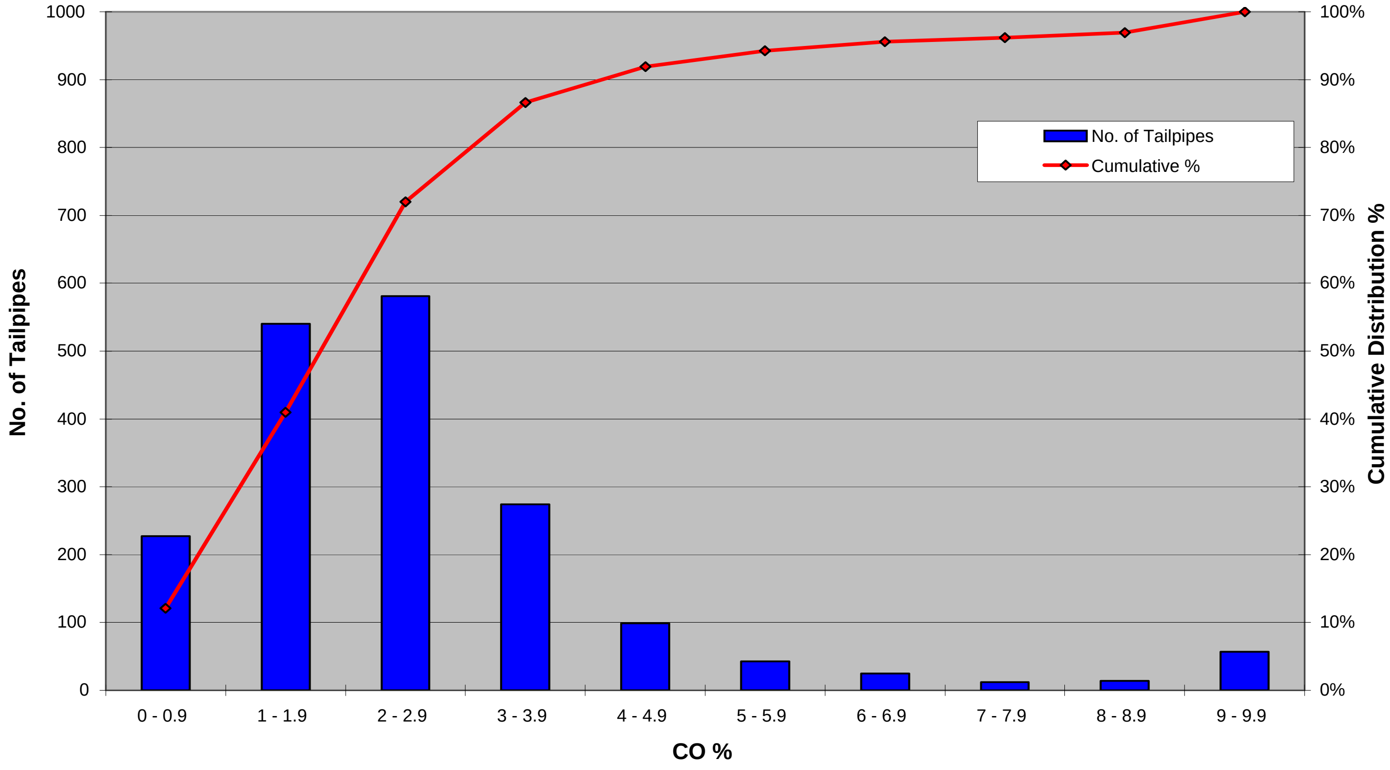


Figure 2.11 - B
Four Stroke CO Data for Tailpipes as Individual Sources

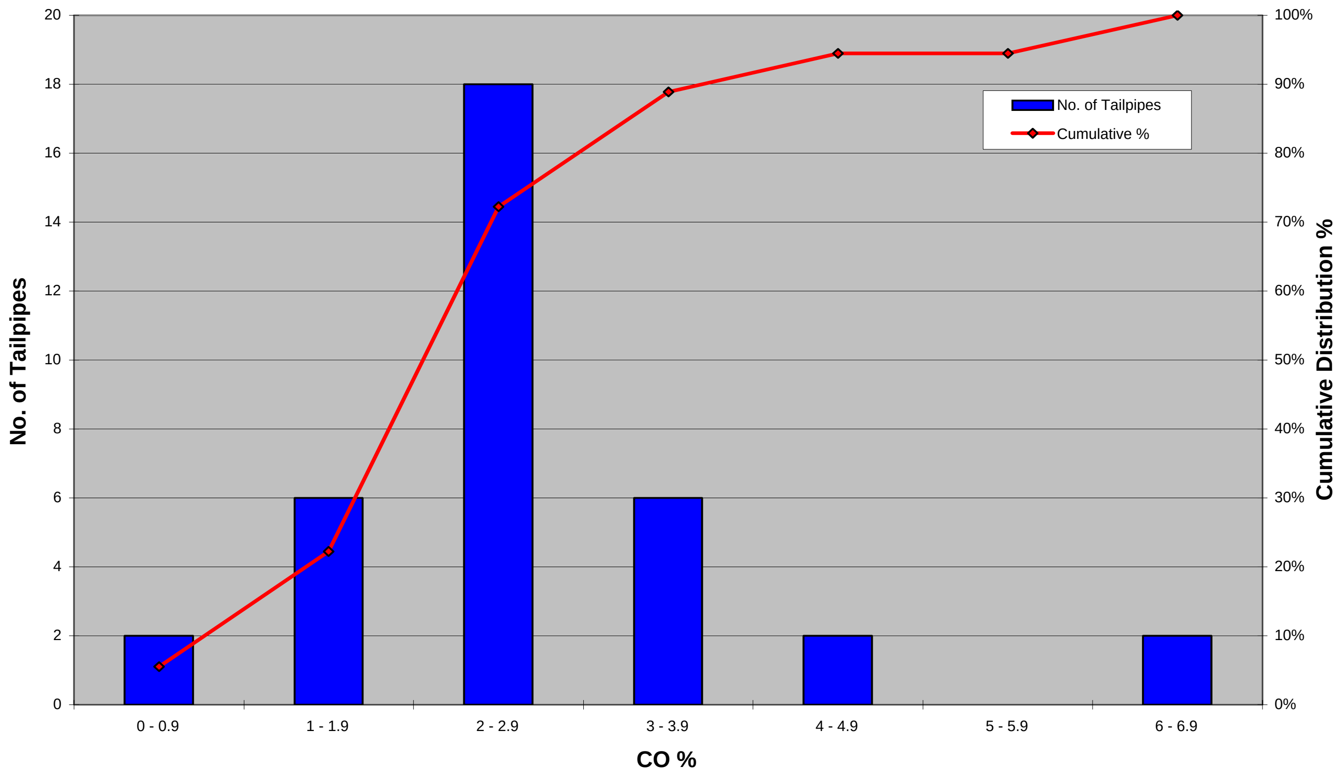


Figure 2.12 - A
Two Stroke HC Data for Tailpipes as Individual Sources

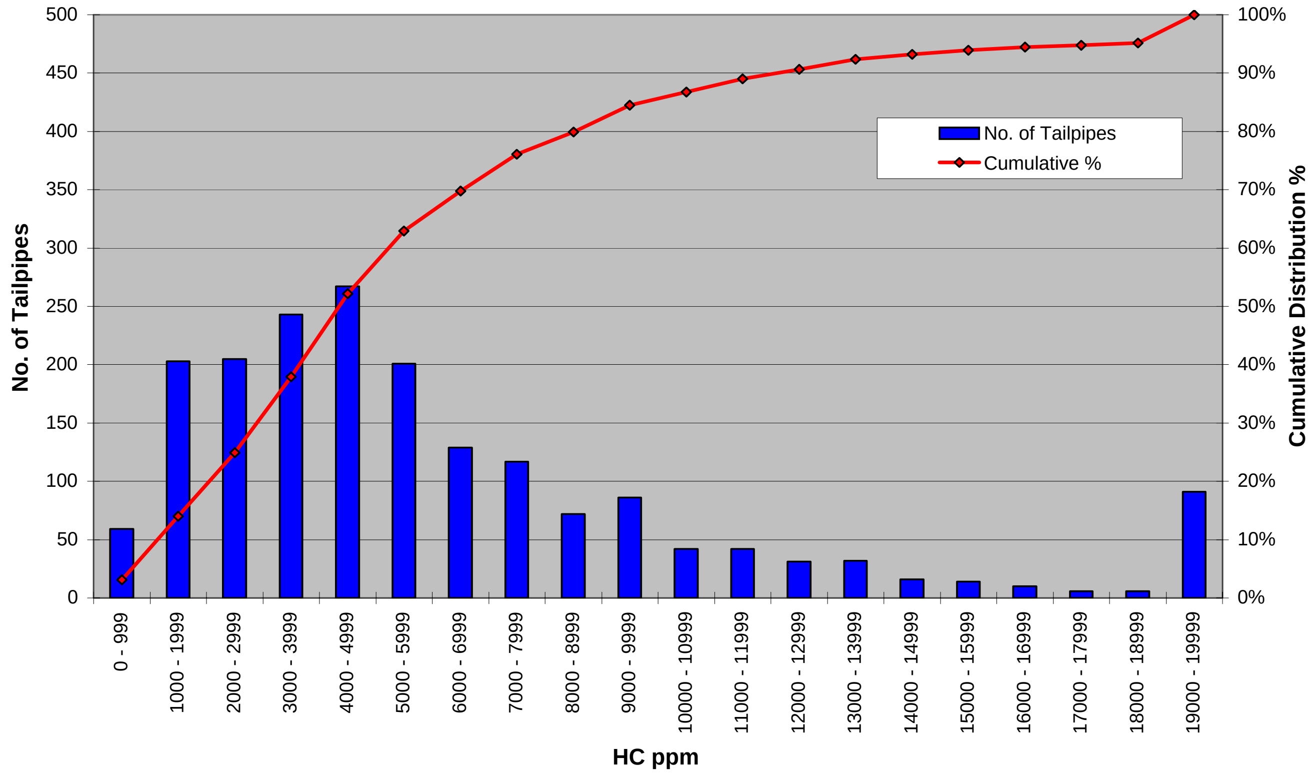
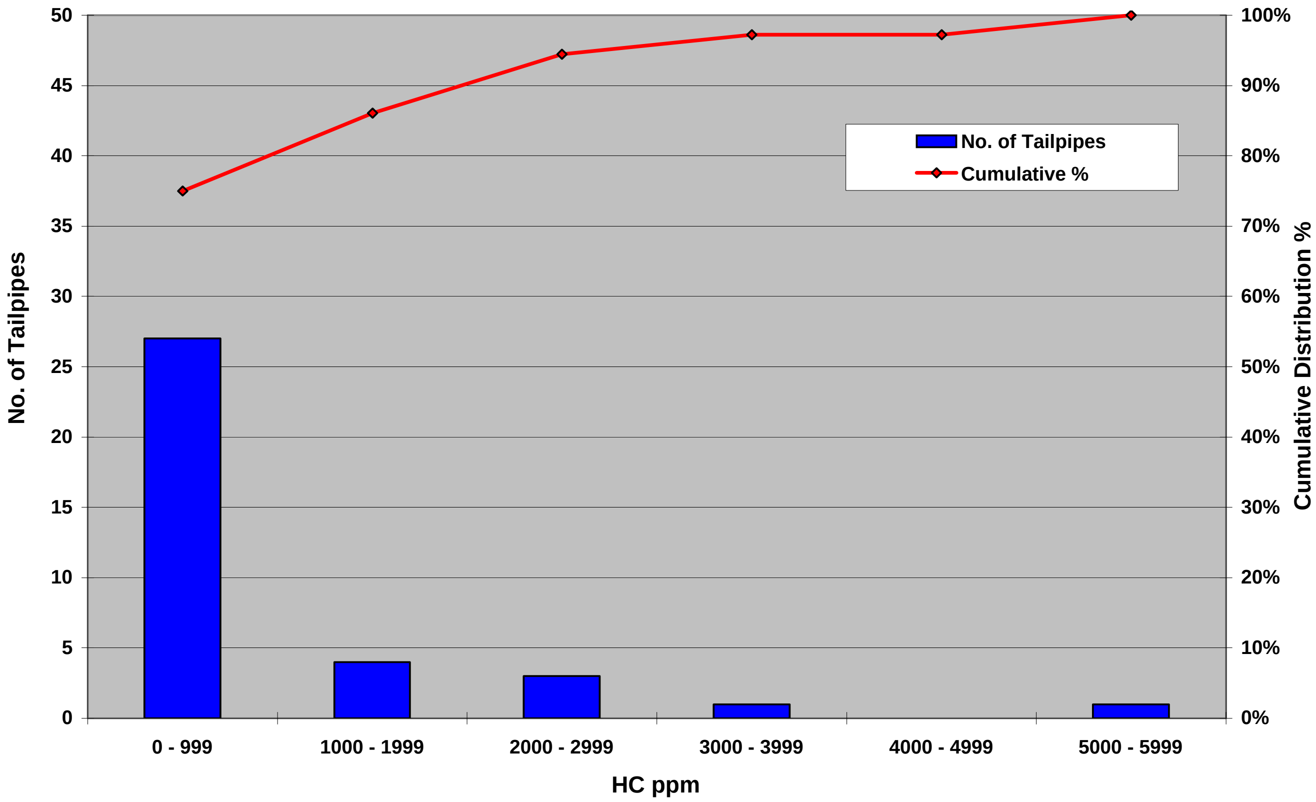


Figure 2.12 - B
Four Stroke HC Data for Tailpipes as Individual Sources



2-2-3 Effect of Engine's Capacity and Operation Period on Emissions

The database, containing the results of the field study, was further utilized to determine the relationships between the average concentration of pollutants and both the engine's capacity and its operation period (measured in terms of the model year). According to their engine's capacity, motorcycles were divided into three categories: 350cc, 175cc, and 125cc. According to the model year, the three categories selected were pre-1980, 1980–1989 inclusive, and 1990–1999 inclusive. The average concentrations of pollutants in emissions were calculated as follows:

Effect of engine capacity on average concentration of pollutants

Engine capacity	No. of tests*	CO (as %)	HC (in ppm)
350 cc	1074	2.32	5637
175 cc	170	2.90	6444
125 cc	712	3.13	7118

It can be seen that smaller engines produce higher concentrations of pollutants. The statistical significance of results indicates that engines 350cc in capacity have lower emissions than other engines. Differences between the other two groups (175cc and 125cc) are statistically insignificant.

Effect of engine model year (i.e. operation period) on average pollutants' concentrations

Category	Manufacturing Year	No. of Tests*	CO (as %)	HC (in ppm)
Category 1	Pre 1980	408	2.76	6535
Category 2	1980-1989	1404	2.54	6100
Category 3	1990-2000	947	2.51	5649

It can be seen that older engines emit more pollutants, especially HC. Statistical analysis indicates that all differences are significant, except for the difference between Categories 2 and 3 when considering average concentration of CO.

2-2-4 Effect of Using Oil-Dosing Pumps

The design of two-stroke engines requires adding a specified quantity of lubricating oil to fuel inside the fuel tank. This mixture goes through the engine where the oil lubricates the engine parts. Since it goes through the fuel combustion process, the oil is subjected to burning and the product of its

* Note that a motorcycle with dual tailpipes undertakes 2 tests that are counted separately

burning exits with emissions. Moreover, the two-stroke engine's design allows a large portion of fuel to be emitted unburned, containing HC and unburned oil particles.

Motorcycle operating instructions state that oil should be mixed with fuel in a specified ratio, otherwise the engine could be damaged if the amount of oil was less than the amount defined in the product specifications. Motorists however do not follow instructions and tend to add excessive quantities of oil in fear of engine damage even though they realize that this increases smoke emission. Operating instructions also recommend the use of oils designated for two-stroke engines since they cause less smoke. However, two-stroke specific oils are more expensive, costing almost twice as much as regular oils; thus motorists favor regular oils even though these oils emit more pollutants.

To overcome the problem of excessive addition of oil to fuel, modern two-stroke engines are designed with a separate oil tank, equipped with a dosing pump that adjusts the quantity of oil being added to fuel according to operation conditions. This method eliminates the need for manual (hence not in proper amounts) addition of oil to fuel. However, the presence of oil-dosing pumps does not in practice prevent manual addition of oil, resulting in even higher smoke density.

In this context, the fieldwork included studying the effect of installing oil-dosing pumps on motorcycle emissions. The study was conducted on a sample of in-use motorcycles.

Installing oil-dosing pumps

Through coordination between EEAA and the Egyptian Light Transportation Manufacturing Company (ELTRAMCO), ten oil-dosing pumps were installed in two-stroke, in-use motorcycles of a most popular make in Egypt, the Jawa 350. The company imported and installed those pumps in 7 motorcycles belonging to the Ministry of Agriculture and 3 motorcycles of Al-Ahram Organization. Each pump and related essential parts cost around £E 340.

Pumps were installed at the company site, where motorists were informed of operating instructions, especially the necessity of using oils specified for two-stroke engines and ensuring sufficient oil quantities are always present in the oil tank. Motorcycles were tested before and after installing oil-dosing pumps.

In one of the motorcycles, the engine was damaged as a result of a defect in the oil-dosing pump, which prevented oil from reaching the engine. The maintenance technicians at the garage immediately took the initiative to uninstall the pumps from the other motorcycles to avoid the same problem from reoccurring. The technical inspection made by ELTRAMCO proved that the pump was damaged as a result of using ordinary oils. The company explained that the high viscosity of ordinary oil leads to blocking of oil passage through the pump thus the oil does not reach the engine.

MORT results

The tables shown below display the results of motorcycle emission measurements before and after installing oil-dosing pumps, when using the proper oil type. The results of comparison of average concentrations of CO and HC at idle speed are discussed below.

Test Results before Installing the Oil Pumps

#	Plate number	HC		CO		Opacity Low speed		Opacity High speed	
		tailpipe 1	tailpipe 2	tailpipe 1	tailpipe 2	tailpipe 1	tailpipe 2	tailpipe 1	tailpipe 2
1	30619	4950	6650	2.4	3.4				
2	30948	1985	1635	4.9	4.2	9.8	10.5	29.9	44.7
3	30903	1995	2985	1.9	8.5	10.0	20.0	30.0	54.1
4	30851	2645	11250	2.9	4.0	34.0	27.0	24.5	22.5
5	30850	11550	20000	8.1	7.0	8.8	5.0	39.0	51.4
6	30744	20000	20000	8.7	9.6	8.5	2.9	44.0	28.0
7	31507	20000	20000	9.6	9.4	13.0	4.0	37.2	30.9
8	130486	6772	11902	2.75	3.67	13.0	21.0	95.0	70.0
9	59148	9315	9106	2.84	2.44	3.5	5.0	37.0	45.0
10	52936	2524	6548	1.75	3.43	9.1	5.5	36.0	35.0

Test Results after Installing the Oil Pumps

#	Plate number	HC		CO		Opacity Low speed		Opacity High speed	
		tailpipe 1	tailpipe 2	tailpipe 1	tailpipe 2	tailpipe 1	tailpipe 2	tailpipe 1	tailpipe 2
1	30619	1545	2635	0.8	1.8				
2	30948	1995	5695	0.79	2.0	2.8	2.9	5.2	3.2
3	30903	1200	4695	0.17	1.9	1.4	5.0	4.5	30.5
4	30851	1998	1993	1.61	1.18	8.0	12.0	5.6	7.0
5	30850	4320	1996	2.1	1.04	2.6	1.9	5.0	5.5

6	30744	9165	8965	2.48	1.64	1.5	0.9	14.0	16.5
7	31507	3115	3841	1.2	1.4	5.0	0.9	3.9	1.75
8	130486	1081	1572	0.35	0.67	4.0	4.0	12.6	3.9
9	59148	3595	3172	1.39	1.18	30.0	22.0	50.5	41.0
10	52936	3213	3850	1.3	1.5	4.0	6.0	45.0	55.0

Hydrocarbons

HC concentration has dramatically dropped after installing oil-dosing pumps in 6 motorcycles. It dropped from 8,000–20,000 ppm to 3,000–9,000 ppm.

The percentage of this reduction ranges between 25%–87%. Conversely, the remaining 4 motorcycles showed a significant increase in HC concentration, becoming more than a double sometimes. It was discovered that motorists persisted in adding oil manually, not satisfied with the oil added by the oil-pump.

Carbon monoxide

Before installing oil-dosing pumps, CO concentration was in the range 10%-18%. After its installation, CO dropped drastically to 0.2%-2.00%. The percentage of CO reduction is 25%–90%, which may be the result of the increase in efficiency of combustion when the addition of oil is regulated.

Smoke opacity

Opacity was measured for only nine (9) motorcycles because one (of the 10 initially planned as sample) was not available at the time of measurement. Measurements were taken at idle and maximum speeds. The following can be concluded:

- Before installing oil-dosing pumps, opacity ranged between 3%–34%, with an average of 12%, at idle speed. At maximum speed, opacity ranged from 23%–95%.
- After installing oil-dosing pumps in 6 motorcycles, opacity dropped to 1%–12% at idle speed. At maximum speed, it dropped to 2%–31%. The percentage of opacity reduction is 40%–94%.
- As for motorcycles in which the pumps were uninstalled, opacity increased by 25%–60%, even doubled in some motorcycles. This was probably because of the excessive addition of oil in fear of engine’s damage.
- It must be noted that when the oil-dosing pumps were installed along with the related essential parts, no other modifications were made in parts that could affect emission composition, mainly the tailpipe, which must have contained residue from pre-modification combustion.

- Because of the test sample's limited number of motorcycles (10), it has been statistically difficult to reach exact conclusions. To further find out the effect of installing oil-dosing pumps in motorcycles, emissions of a sample of motorcycles originally equipped with oil-dosing pumps (Sample A) were compared with emissions of two other motorcycle samples (Samples B and C) that do not have oil-dosing pumps.
- Sample A is quite small, comprising only 44 motorcycles, as compared to Sample B, 170 motorcycles, and sample C, 712 motorcycles. The average levels of pollutants concluded are shown in the table below.

Motorcycle Type	Sample size	CO	HC
Type (A) With oil dosing pumps	44	2.18	5348
Type (B) Without oil dosing pumps	170	2.88	6444
Type (B) Without oil dosing pumps	712	2.91	7134

It can therefore be concluded that oil-dosing pumps lead to a reduction in average CO concentration by 24%–25%, and a reduction in average HC concentration by 17%–25%.

It is important to mention that the three samples included motorcycles of different model years and engine capacity, which are two factors that affect the concentration of pollutants.

Chapter Three
Emission Standards

Setting emission standards is one of the most effective ways to control motorcycle pollutants. There are two types of emission standards:

- Emission standards for new motorcycles before allowing them in the market
- Emission standards for in-use motorcycles

3-1 New Motorcycles Emission Standards

Emission standards for new motorcycles define the maximum levels of emissions that are permitted from new motorcycles before they are introduced into the market. Motorcycle manufacturers and assembling factories are required to comply with these standards, enforced through production licensing procedures and sample testing of new motorcycles.

New motorcycles standards are the principal method to guarantee that engines use up-to-date techniques of polluting-emissions control. Examples of how standards are utilized to control new motorcycles can be seen in previous experiences of other countries. Standards applied in the US have resulted in the termination of two-stroke engine production and use. Contrarily, in EU countries, emission standards permit production and use of two-stroke engines without requiring effective methods to control pollutants.

On the other hand, some European countries, Switzerland and Austria, set standards that are stricter in view of environmental protection.

Such standards typically define maximum limits in terms of units of weight (grams/kilometer), when operating motorcycles on a dynamometer that permits operating the engine at different speeds and loads according to a standard test cycle. Sometimes, standards for new motorcycles are defined in units of pollutant concentration in emissions. This is the case in Switzerland and Indonesia.

Below is a summary of emission standards for new motorcycles in some countries.

Emission Standards for New Motorcycles

Country	CO (gram/kilometer)	HC (gram/kilometer)	Remarks
United States	12	2–5	According to engine capacity
California	12	1–1.4	
European Union	17-40	11–17	
Austria			
Two-stroke	8	7.5	
Four-stroke	12	3	
India	30	12	
Switzerland	1	200	
Indonesia			
Two-stroke	4.5	3000	
Four-stroke	4.5	2400	

3-2 Emission Standards for In-use Motorcycles

Standards for in-use motorcycles are usually set to define the maximum limits of pollutant concentration in emissions from motorcycles that are in actual use. The standards are checked either during motorcycle license renewal or on the road. For in-use motorcycles, the focus is on CO and HC concentrations. Due to technical considerations discussed later, enforcing motorcycles to comply with emission standards has limited viability and is not guaranteed. As a result, few countries implement standards for in-use motorcycles, including Taiwan, Korea, Thailand, and the State of Arizona in the USA. Some countries set unified standards for all motorcycles, while others set different standards depending on engine type (whether two- or four-stroke), engine capacity, and model year. In-use standards are set based on a number of factors related to motorcycle usage and maintenance:

- The existing environmental status and air sensitivity to specific pollutants characteristic of motorcycle emissions (particulate matter, HC, etc.).

- The extent of motorcycles' contribution to pollution in comparison with other sources, which depends on the number and type of motorcycles, the manner and frequency of usage, and maintenance efficiency.
- Environmental goals related to reduction of air pollution.
- Economic and social considerations related to application of specified emission standards.

The table below shows in-use emission standards in some countries

Motorcycles in-use emission standards

Country	CO (g/km)	HC (g/km)	Remarks
Taiwan	4	9000	7000 for new motorcycles
Thailand	6	14000	Recommended
Arizona, USA			
Two stroke	5.5	18000	
Four stroke	5	1800	
Japan	2.5	7800	

3-3 Emission Standards in Egypt

Environmental Law No. 4/1994 prohibits use of "vehicles" whose emissions exceed standards specified in its executive regulations. But neither the law nor its executive regulations specify emission standards that put controls over motorcycle importers and local manufacturers. Enforcing importers and local manufacturers to ensure compliance of new motorcycles with emission standards therefore necessitates cooperation among concerned ministries. Setting in-use motorcycle standards is, however, within the domain of MOE and EEAA responsibilities in coordination with other concerned ministries, while enforcing compliance with standards is within the responsibility of the Ministry of Interior. Below are suggested separate emission standards for new and in-use motorcycles in Egypt.

3-3-1 Proposed Emission Standards for New Motorcycles

It is proposed that emission standards for new motorcycles include maximum CO and HC concentration values that permit most four-stroke motorcycles to comply but not two-stroke motorcycles. It was earlier recommended that new motorcycles, both imported and locally manufactured, comply with emission standards applied in European countries—namely Switzerland and Austria—that are greatly concerned with environmental protection from harmful motorcycle emissions, thus restrict motorcycles to those with four-stroke engines equipped with up-to-date emission-control facilities.

Proposed emission standards for new motorcycles are as follows:

CO:	2.5%
HC:	900 ppm
Opacity:	5%

These recommendations were presented to and discussed with concerned parties in February 1999. Local manufacturers asked for a grace period of 3–5 years to abide by these standards. Along the line of action that was taken for new vehicles, a cooperation agreement should be signed among concerned authorities to apply emission standards of production and importing of motorcycles.

3-3-2 In-use Emission Standards

Environmental Law No. 4/1994 prohibits use of "vehicles" with emissions exceeding the limits defined in its executive regulations. The definition of vehicles in Article 1 of this law includes motorcycles. Article 37 of its executive regulations defines maximum levels of pollutants in emissions of vehicles in general, distinguishing between in-use vehicles and new vehicles (at that time) licensed as of 1995. Legally, motorcycles should comply with these standards unless other standards are issued, which is the main reason for conducting this study.

From a practical viewpoint, motorcycle emission standards are defined to achieve a motorcycle compliance rate of 70%–80%. In this case the rate of failure in emission tests would not exceed 20%–30%. Compliance rate will be used to determine the suitability of emission standards to real-life application.

3-4 Standards and Compliance Rates

This section of the report discusses the effect of enforcing motorcycles to comply with emission standards, in terms of compliance rates and the expected reduction in emission. Several situations will be discussed:

- Assuming the vehicle emission standards stated in the executive regulations of Law No. 4/1994 are applied to motorcycles, treating them as a type of vehicles.
- Setting national emission standards according to the test measurement results with specified goals in mind to be achieved such as reducing motorcycle pollutants by a specific rate.

3-4-1 Applying Standards of the Executive Regulations

Article No. 37 of Law No. 4/1994 defines the maximum limits of pollutants' levels as follows:

Pollutants	Pre 1995	1995 and after
CO	7%	4.5%
HC	1000 ppm	900 ppm
Opacity	65%	50%

The concentrations of CO and HC are measured at idle speed (600–950 rpm*). Opacity is measured at maximum engine speed (unloaded). Standards of relatively new vehicles (after 1995) are stricter than in-use standards, since new vehicles use modern engines with emission control tools hence should have fewer emissions.

In Egypt, there is no significant technical difference between pre-1995 motorcycles and later models. This is explained by the fact that motorcycles have been produced for a long period of time without any significant modification in specifications or engine type. Besides, most modern locally manufactured motorcycles in Egypt still have two-stroke engines, and the only major modification in them is the addition of an oil-dosing pump. However, expected compliance rates will be estimated according to motorcycle model year when these standards are applied. It is worth noting that 75% of the test sample are pre 1995 motorcycles.

Below are the expected compliance rates in case the standards followed are those defined in the executive regulations for CO, HC, and opacity. Graphs of cumulative distributions for motorcycles and emissions were prepared in order to evaluate the following:

- Compliance rates at each of the suggested standards, and

* Revolutions per minute

- Expected emission reduction when enforcing motorcycles to comply with these standards, assuming that a certain reduction in emission concentration results in an equal reduction in the emission quantity.

Carbon monoxide

Compliance rates were estimated using computerized methods for both pre-1995 models and later models. Compliance rates were also estimated for both two- and four-stroke engines according to model year.

In case of applying CO standards of the executive regulations with regards to the 2 model-year categories, compliant motorcycles will represent approximately 91% for pre-1995 motorcycles and 96% for 1995 and later motorcycles. It is expected that enforcing motorcycles to comply with CO standards will reduce CO emissions by 27% in old motorcycles and 15% in new motorcycles. Below is a summary of estimated compliance rates and expected emission reduction in the two motorcycle categories.

Engine Type	Compliance Rate (%)		Emission Reduction (%)	
	Pre 1995	1995 & later	Pre 1995	1995 & later
Two-stroke motorcycles	92	96	25	15
Four-stroke motorcycles	87	97	24	9
All motorcycles	91	96	27	15

Notice that compliance rates are very high compared to rates in most countries, which set compliance rates in the range 70%–80%. These high compliance rates are due to the relaxed standards in Law 4/1994. Therefore, standard rates should be reduced to give a compliance rate of approximately 80%.

To estimate maximum CO limits either for all motorcycles as a single category or for two- and four-stroke motorcycles independently, the cumulative distribution for motorcycles and CO emissions, shown in figure 3–1, was used. It can be seen that CO standard should be around 3.5% to give a compliance rate of 80%.

Figure 3-1
Cumulative Distribution of CO Emissions from All Motorcycles

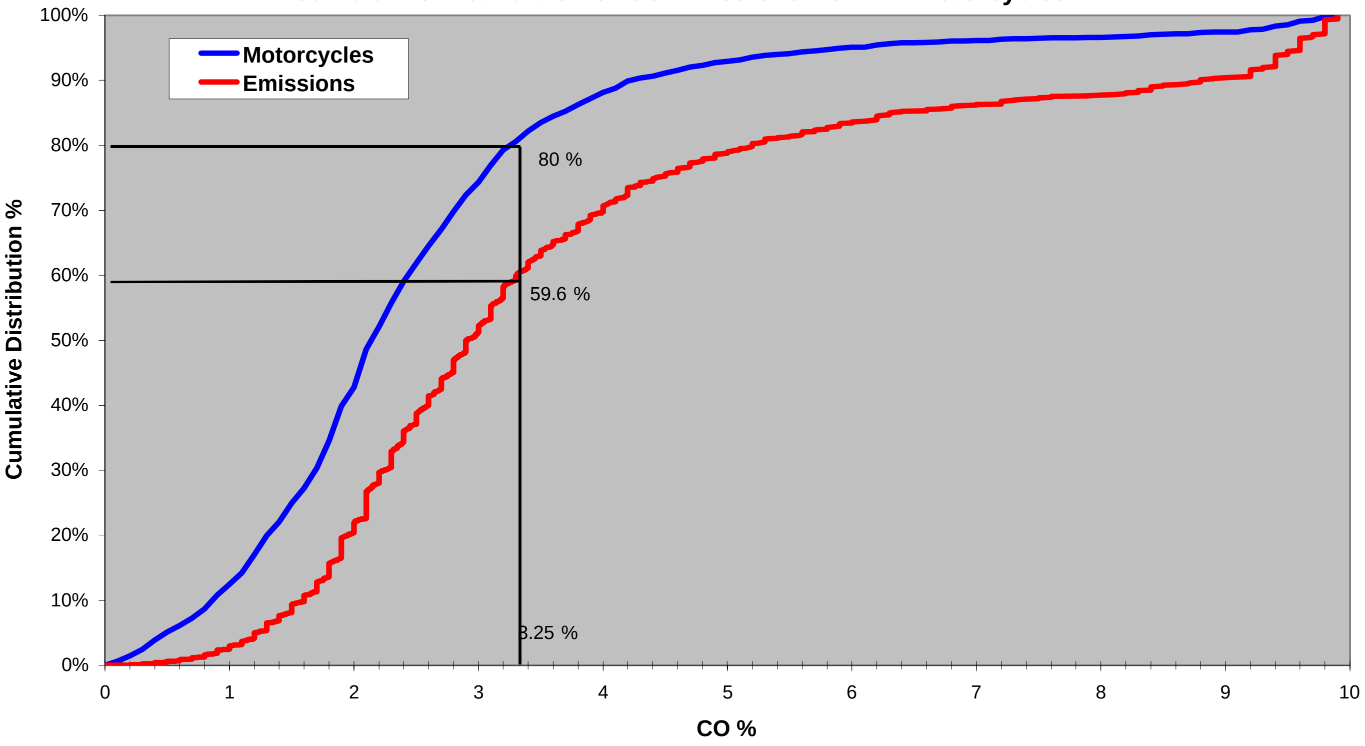


Figure 3-3
Cumulative Distribution of Opacity at Maximum Speed Data from Motorcycles

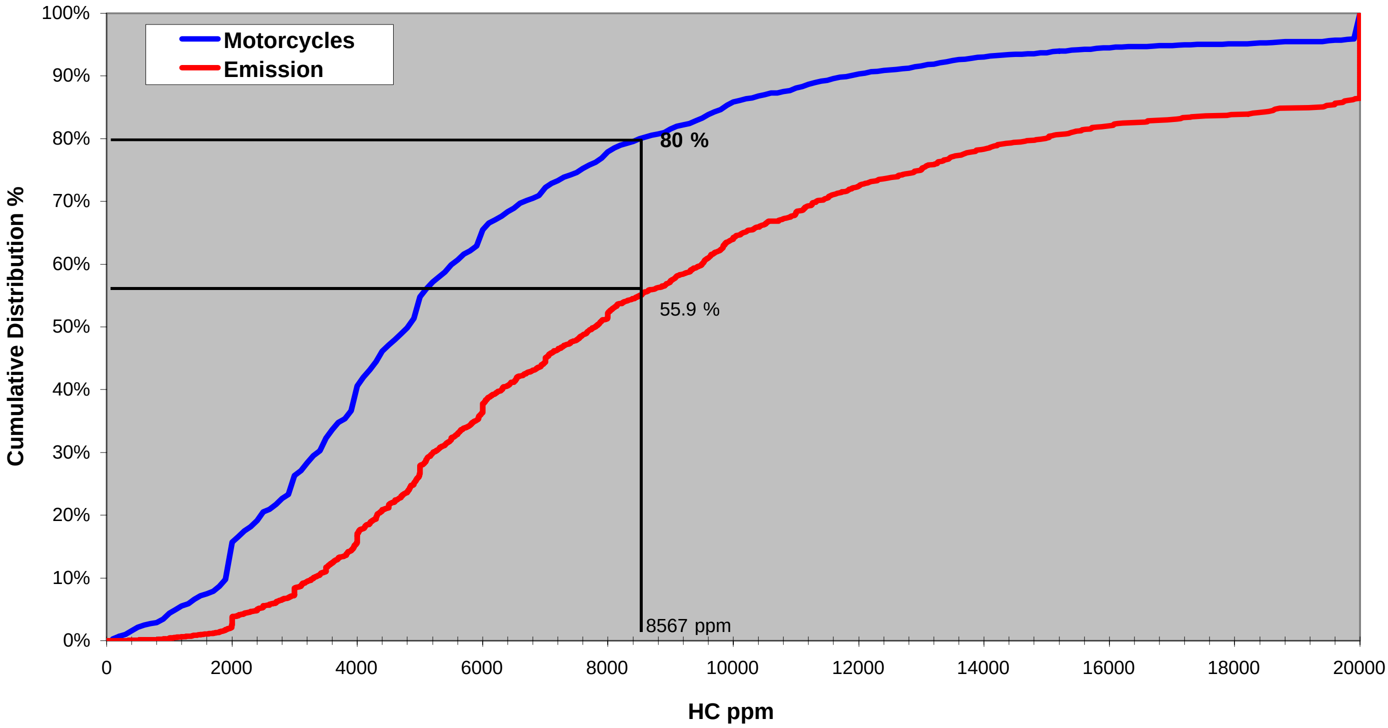
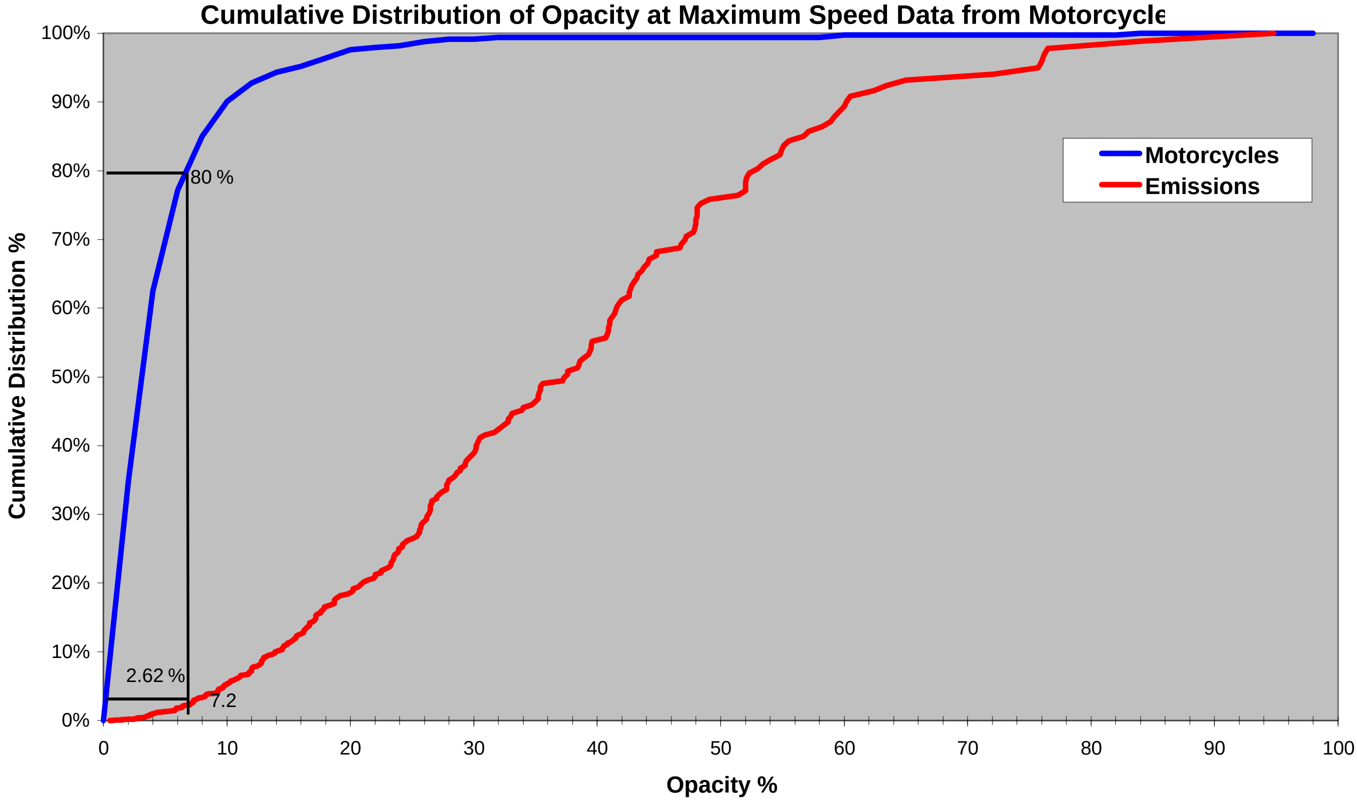


Figure 3-3
Cumulative Distribution of Opacity at Maximum Speed Data from Motorcycle



Enforcing motorcycles to comply with this proposed concentration is expected to reduce CO emissions by 40%.

Since measurements were taken from a small sample, and to avoid having a low compliance rate upon applying standards practically on motorcycles, it is proposed to set the CO maximum limit to 4%. From the motorcycles database, the expected compliance rate would be 87% and the expected emission reduction 30%.

For comparison purposes, the table below shows CO standards in other countries.

Country	CO concentration (%)	Remarks
Taiwan	4.5	
Korea	3.6	for new motorcycles
Thailand	6.0	proposed
Arizona, USA	5.0	

<u>Hydrocarbons</u>

Model years were considered when estimating compliance rate for two- and four-stroke motorcycles.

In case of applying the executive regulations' standards (900–1000 ppm), the total compliance rate is expected to be roughly 4%, which is a very low rate because the executive regulations' standards do take into account two-stroke motorcycles. Below are the compliance rates and the expected emission reduction when enforcing motorcycles to comply with these standards.

Engine Type	Compliance Rate (%)	Emission Reduction (%)
Two-stroke motorcycles	4	0
Four-stroke motorcycles	60	8
All motorcycles	4	0

It is worth noting that the compliance rate of four-stroke motorcycles, 60%, is relatively low because motorcycle engines are generally not well tuned up. The compliance rate is expected to rise substantially if motorcycle engines are tuned up.

Figure 3-2 illustrates that in order to achieve a compliance rate of 80%, HC standards should be around 8300 ppm. The expected HC emission reduction would be 45% when all motorcycles comply with these standards.

The proposed standard for maximum HC concentration is 9000 ppm, which should reduce emissions by 30%. HC standards in some countries are as follows:

Country	HC Concentration (ppm)	Remarks
Taiwan	9000	
Korea	4500	for new motorcycles
Thailand	14000	proposed
Arizona (in the US)	18000 1800	for two-stroke motorcycles for four-stroke motorcycles

<u>Opacity</u>

Standards in the executive regulations for smoke opacity measured at maximum acceleration are 50%–65%. When these standards are applied, approximately 90%–98% of two-stroke motorcycles will be able to comply with these standards, and PM will drop by 2.5%.

Opacity rates measured for the test sample was very low compared to standards defined in the executive regulations of Law No. 4/1994 because of the following:

1. Standards in the executive regulations are too relaxed.
2. Motorcycle emissions tend to have a bluish or white color due to unburned fuel and oil. This causes opacity readings to be low since opacity is measured as a degree of "blackness". Technical references do not mention any defined opacity standards for in-use motorcycle emissions in other countries.

Chapter Four
Summary and Recommendations

A summary of the field study and relevant scientific work is presented in this section. Suggested alternative solutions to control motorcycle pollution are then discussed, followed by recommendations for the work plan during the next phase.

4-1 Summary and Conclusions

Based on scientific facts and the field measurements taken, the following can be concluded:

1. The study confirmed that emission rates are higher for two-stroke motorcycles than for four-stroke ones. The study also emphasized the pressing need to face this problem, particularly since two-stroke motorcycles make up more than 95% of motorcycles in Egypt.
2. In-use standards can be utilized as a tool to either permit only four-stroke motorcycles or allow two-stroke motorcycles as well (standards to be applicable to both new and in-use motorcycles).
3. There are two alternatives for in-use motorcycles:
   - To permit use of <u>four-stroke motorcycles only</u>. If this alternative is selected, it is essential to study the economic and social impacts of prohibiting two-stroke motorcycles.
   - To permit use of <u>two-stroke motorcycles</u> as well. If this alternative is selected, it is necessary to study methods to reduce emissions of this type of motorcycles to a minimum. It is difficult however to enforce two-stroke motorcycles' compliance with emission standards regardless of the degree of strictness of the selected standards, for technical considerations related to the nature of motorcycles emissions and emission testing procedures.

4. The reasons for the ineffectiveness of enforcing two-stroke motorcycles to comply with environmental standards are summarized below.

- **Routine inspection is not useful**. Measurements are affected by the nature and quantity of oil mixed with the fuel at the time of inspection. Motorcycle owners could easily adjust these two factors before the motorcycle undergoes inspection thus ensuring success in the emission test regardless of actual compliance of the motorcycle on the road.
- **Results of emission tests are not sufficiently reliable**, due to the following reasons:
    a. Inconsistency of HC and CO readings for the same motorcycle due to inherently unstable/irregular idle speed, at which CO and HC measurements should be taken.
    b. Difficulty in getting accurate opacity readings at maximum speed, since motorcycle engines do not generally have speed governors (as opposed to diesel engines). As a result, there is great variation in maximum speed hence opacity reading. Furthermore, a number of technical factors have to be considered when interpreting the opacity readings, since different opacity measuring devices do not use the same method and unit of measurement.
- **Technical difficulties in emission testing procedures**. These increase effort, time, and cost. Major difficulties are described below.
    a. Due to the high concentration of unburned fuel and oil in exhaust, and their resulting precipitation in the test equipment components, false readings may be taken. To avoid false readings, very frequent filter replacement is necessary.
    b. Testing motorcycles inside vehicle emissions testing (VET) stations significantly raises the level of indoor pollution, hence requiring either a ventilation system upgrade or conducting tests outside the stations.

Consequently, the majority of developed countries do not test emissions for in-use motorcycles. Some countries do not even define in-use standards for motorcycles. The focus instead is on enforcing new motorcycles to comply with defined emission standards before the motorcycles are introduced into the market.

4-2 Suggested Alternatives

The following suggestions present alternatives and their associated procedures to combat air pollution resulting from motorcycle emissions. Suggested solutions deal with currently in-use as well as new motorcycles.

4-2-1 In-use Motorcycles

Reduction of harmful emissions resulting from two-stroke motorcycles which are currently in-use can be achieved through implementing one or more of the alternatives suggested below.

A. Improving and upgrading two-stroke motorcycle usage

Emissions could be reduced by approximately 30% by using appropriate oils and correct oil/fuel mixture ratios. This could be achieved, with varying levels of success, through:

1. **Promoting awareness among motorcyclists of the importance of using two-stroke engines oils, while providing a suitable method for controlling the quantity of oil when it is manually added.**

   Positive results from applying this alternative are hindered by the following:

   - Due to the importance of lubricating engine parts to reduce corrosion, motorcycle owners are inclined to raise oil percentage to the maximum operationally possible, in order to extend the engine's life span.
   - Motorcycles prefer to pay extra for additional oil mixed to fuel rather than run the risk of engine damage due to oil shortage.
   - It is difficult to convince motorcycle owners to use oils specifically indicated for two-stroke engines because they cost nearly twice as much as regular oils.
   - It is difficult to accurately control the ratio of oil mixed to fuel due to motorists' ignorance of the exact fuel quantity in the tank. Graded oil cans suitable for metering the small oil quantities needed are not available.

   Success of this alternative therefore relies on cutting down prices of two-stroke-engine oils to prices compatible with regular oil or less and providing a convenient way to calibrate oil added manually to fuel.

2. Preparing the mixture of oil and fuel at fueling stations

Implementing this alternative will help overcome the problem of adjusting the mixture and using proper oils. Some technical problems may occur when different mixture ratios are required for different motorcycles. Success of this alternative requires the existence of a suitable infrastructure network at oil companies and distribution stations. The mixture should be available in competitive prices compared to the cost of mixing regular oil manually.

3. Installing oil-dosing pumps

This suggestion is viable, but installing oil-dosing pumps will not stop motorists from adding oil manually. Success of this alternative requires subsidizing the costs of installing oil-dosing pumps. It was possible to reduce the cost from £E 340 to £E 200. Oils for two-stroke engines should also be made available at moderate prices.

4. Upgrading engines through modifying ignition and fueling systems

Two-stroke engines can be upgraded through modifying their ignition and fueling systems, such as use of electronic ignition and fuel injectors, in order to reduce emissions. Engineering and technological studies should be used to determine the best system from the technical and economic points of view. Subsidy is required to cover most or all of the costs of upgrade.

5. Encouraging new initiatives

There are several new initiatives that reduce emissions. These include use of synthetic oils and conversion to compressed natural gas. Success of this alternative requires financial subsidy for capital investments and operating costs.

The field study showed that it is both difficult and ineffective to enforce any of the above suggestions through setting in-use standards and conducting routine emissions testing. Hence, success in implementing any of the above alternatives relies on the availability of required financial subsidy. Considering the differences in the expected levels of emissions, a feasibility study is required to choose the best of these alternative solutions taking into consideration technical, economical, and environmental aspects.

B. Conversion to four-stroke engines

Emissions can be drastically reduced by more than 90% if two-stroke engines are replaced with four-stroke engines in motorcycles. Such a solution can be accomplished by setting emission standards with which only four-stroke engines can comply, and issuing administrative resolutions prohibiting two-stroke motorcycle licensing or use. Many environmental and economic benefits would ensue, mainly a cutback in operating costs due to reduced fuel and oil consumption.

On the other hand, it is expected that such a requirement would meet great opposition from most two-stroke motorcycle owners for economic reasons, namely those related to purchasing new motorcycles and discarding the old two-stroke ones.

For this approach to be effective, it is therefore recommended to simultaneously work in several parallel directions, including:

1. **Gradual prohibition of two-stroke motorcycles in cities**

   Make prohibition gradual, by first prohibiting two-stroke motorcycles in some crowded areas of major cities, such as Cairo and Alexandria, then in whole cities exempting open and remote areas. Concerned authorities, the Ministry of Interior and governorates, should issue administrative resolutions in this regard. In use motorcycle standards should be gradual as well. Two stroke motorcycles will be permitted only in the first phases.

2. **Installing four-stroke engines in place of four-stroke engines**

   Upgrading old motorcycles by installing four-stroke engines in place of two-stroke ones reduces costs, because it is cheaper than new motorcycle purchase and avoids the problem of discarding old motorcycles. Effective implementation can be guaranteed through:

   - Providing technical support to motorcycle manufacturers in performing the suggested modification.
   - Partial or full subsidy for upgrade expenses, with priority given to urban regions. Finance could be through one of the environmental projects as well as the Social Fund.
   - Promoting local assembly and/or import of four-stroke engines, by reducing taxes and customs on the engines and their components, at the same time increasing these for two-stroke engines and their components.

   In use standards can then be used as a tool to allow four-stroke engines only, taking into consideration the time needed to convert all two stroke motorcycles. In this case, current standards defined in the executive regulations could be applied without modification if the time of their implementation coincides with the timeframe of the plan for conversion to four stroke engines.

ELTRAMCO has already succeeded in replacing the two-stroke engine of the 175cc model with a four-stroke engine onto the same chassis. This has resulted in a £E 800 increase in the motorcycle price. It is still not possible to replace the 350-cc two-stroke engine due to technical difficulties, namely finding a substitute four-stroke engine.

4-2-2 New Motorcycles

It is suggested that emission standards for new motorcycles include the strictest limits for CO and HC emissions in such a way that most four-stroke motorcycles can comply but not two-stroke ones. To implement emission standards for new motorcycles, it is necessary to sign a cooperation agreement among concerned authorities similar to that signed for new vehicles.

At the same time, in-use standards should be effected as soon as feasible since they would be sufficient to enforce production/import of four-stroke engines even if they do not include advanced emission control techniques. In-use standards can thus be utilized as a first step to pave the way for necessary arrangements later to enforce emission standards for new motorcycles.

The proposed emission standards for in-use motorcycles are as follows.

CO	2.5%
HC	900 ppm
Opacity	5%

4-3 Recommendations

1. An integrated plan of action should include the following main tasks:

- Preparing a comprehensive feasibility study that takes into consideration the technical, economic, and environmental aspects, in order to compare the main alternatives, namely to:
  a. Continue using two-stroke motorcycles, at the same time implementing the maximum emission reduction measures.
  b. Convert to four-stroke engines, carrying out necessary measures.
- Inviting concerned parties to participate in selecting the best alternative in view of the techno-economic-environmental feasibility study, and to agree on the timeframe for implementing agreed measures.
- Issuing environmental standards for new- and in-use motorcycles in view of feasibility study results, which will be used to determine whether or not two-stroke motorcycles will be allowed to comply as well. Dates of enforcement of standards will be defined according to the timeframe agreed by concerned parties.

Suggested Implementation Plan

Tasks	Months					
	1	2	3	4	5	6
Preparing feasibility study						
Decision making and planning for implementation program alternatives						
Issuing standards						
Starting program						

2. Since there are economic and social factors to be considered with respect to the motorcycle emissions issue, a preliminary meeting is recommended, to be attended by representatives of concerned parties, namely the Federation of Egyptian Industries, Association of Chambers of Commerce, and the Ministries of Petroleum, Interior, Industry, Economy, and Foreign Trade. The meeting's aim is to present results of this report and suggested mitigation plan, and highlight the importance of cooperation and input from these parties to supply required information for feasibility study preparation.