Division 44
Water, Energy, Transport

Inspection & Maintenance and Roadworthiness

Module 4b

Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities

giz Transport Policy Advisory Services

On behalf of
Federal Ministry
for Economic Cooperation
and Development

OVERVIEW OF THE SOURCEBOOK

Sustainable Transport:

A Sourcebook for Policy-Makers in Developing Cities

What is the Sourcebook?

This *Sourcebook* on Sustainable Urban Transport addresses the key areas of a sustainable transport policy framework for a developing city. The *Sourcebook* consists of more than 30 modules mentioned on the following pages. It is also complemented by a series of training documents and other material available from http://www.sutp.org (and http://www.sutp.cn for Chinese users).

Who is it for?

The *Sourcebook* is intended for policy-makers in developing cities and their advisors. This target audience is reflected in the content, which provides policy tools appropriate for application in a range of developing cities. The academic sector (*e.g.* universities) has also benefited from this material.

How is it supposed to be used?

The *Sourcebook* can be used in a number of ways. If printed, it should be kept in one location, and the different modules provided to officials involved in urban transport. The *Sourcebook* can be easily adapted to fit a formal short course training event, or can serve as a guide for developing a curriculum or other training program in the area of urban transport. GIZ has and is still further elaborating training packages for selected modules, all available since October 2004 from http://www.sutp.org or http://www.sutp.cn.

What are some of the key features?

The key features of the *Sourcebook* include:

- A practical orientation, focusing on best practices in planning and regulation and, where possible, successful experiences in developing cities.
- Contributors are leading experts in their fields.
- An attractive and easy-to-read, colour layout.
- Non-technical language (to the extent possible), with technical terms explained.
- Updates via the Internet.

How do I get a copy?

Electronic versions (pdf) of the modules are available at http://www.sutp.org or http://www.sutp.cn. Due to the updating of all modules print versions of the English language edition are no longer available. A print version of the first 20 modules in Chinese language is sold throughout China by Communication Press and a compilation of selected modules is being sold by McMillan, India, in South Asia. Any questions regarding the use of the modules can be directed to sutp@sutp.org or transport@giz.de.

Comments or feedback?

We would welcome any of your comments or suggestions, on any aspect of the *Sourcebook*, by e-mail to sutp@sutp.org and transport@giz.de, or by surface mail to:

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65726 Eschborn, Germany

Further modules and resources

Further modules are under preparation in the areas of *Energy Efficiency for Urban Transport, Urban Transport and Health* and *Public Transport Integration.*

Additional resources are being developed, and Urban Transport Photo CD-ROMs and DVD are available (some photos have been uploaded in http://www.sutp.org – photo section). You will also find relevant links, bibliographical references and more than 400 documents and presentations under http://www.sutp.org, (http://www.sutp.cn for Chinese users).

Modules and contributors

(i) *Sourcebook Overview and Cross-cutting Issues of Urban Transport* (GTZ)

Institutional and policy orientation

1a. *The Role of Transport in Urban Development Policy* (Enrique Peñalosa)

1b. *Urban Transport Institutions* (Richard Meakin)

1c. *Private Sector Participation in Urban Transport Infrastructure Provision* (Christopher Zegras, MIT)

1d. *Economic Instruments* (Manfred Breithaupt, GTZ)

1e. *Raising Public Awareness about Sustainable Urban Transport* (Karl Fjellstrom, Carlos F. Pardo, GTZ)

1f. *Financing Sustainable Urban Transport* (Ko Sakamoto, TRL)

1g. *Urban Freight in Developing Cities* (Bernhard O. Herzog)

Land use planning and demand management

2a. *Land Use Planning and Urban Transport* (Rudolf Petersen, Wuppertal Institute)

2b. *Mobility Management* (Todd Litman, VTPI)

2c. *Parking Management: A Contribution Towards Liveable Cities* (Tom Rye)

Transit, walking and cycling

3a. *Mass Transit Options* (Lloyd Wright, ITDP; Karl Fjellstrom, GTZ)

3b. *Bus Rapid Transit* (Lloyd Wright, ITDP)

3c. *Bus Regulation & Planning* (Richard Meakin)

3d. *Preserving and Expanding the Role of Non-motorised Transport* (Walter Hook, ITDP)

3e. *Car-Free Development* (Lloyd Wright, ITDP)

Vehicles and fuels

4a. *Cleaner Fuels and Vehicle Technologies* (Michael Walsh; Reinhard Kolke, Umweltbundesamt – UBA)

4b. *Inspection & Maintenance and Roadworthiness* (Reinhard Kolke, UBA)

4c. *Two- and Three-Wheelers* (Jitendra Shah, World Bank; N.V. Iyer, Bajaj Auto)

4d. *Natural Gas Vehicles* (MVV InnoTec)

4e. *Intelligent Transport Systems* (Phil Sayeg, TRA; Phil Charles, University of Queensland)

4f. *EcoDriving* (VTL; Manfred Breithaupt, Oliver Eberz, GTZ)

Environmental and health impacts

5a. *Air Quality Management* (Dietrich Schwela, World Health Organization)

5b. *Urban Road Safety* (Jacqueline Lacroix, DVR; David Silcock, GRSP)

5c. *Noise and its Abatement* (Civic Exchange Hong Kong; GTZ; UBA)

5d. *The CDM in the Transport Sector* (Jürg M. Grütter)

5e. *Transport and Climate Change* (Holger Dalkmann; Charlotte Brannigan, C4S)

5f. *Adapting Urban Transport to Climate Change* (Urda Eichhorst, Wuppertal Institute)

Resources

6. *Resources for Policy-makers* (GTZ)

Social and cross-cutting issues on urban transport

7a. *Gender and Urban Transport: Smart and Affordable* (Mika Kunieda; Aimée Gauthier)

About the author

Reinhard Kolke is an engineer of environmental and energy science. From 1993 to 2004, he has worked at the German Federal Environmental Agency (UBA) as an expert for emission reduction and fuel efficiency in road traffic. In addition to his tasks at the Federal Environment Agency, he was on secondment to the Federal Ministry for the Environment and had an advisory function for the European Commission in the accession countries Lithuania and Estonia. In 2004, he obtained a PhD in engineering from the mechanical engineering faculty at Otto-von-Guericke University in Magdeburg. Between 2004 and 2007, Dr Reinhard Kolke headed the research and development department at HJS Fahrzeugtechnik GmbH & Co KG in Menden (Sauerland), a medium-size company which develops, produces and distributes exhaust gas purification systems and diesel particle filters. In 2007, Dr Reinhard Kolke became Director of the ADAC strategic business unit Test and Technical Affairs. For the benefit of consumers, ADAC conducts crash tests, emission tests and product tests using state-of-the-art technology and devices.

Module 4b

Inspection & Maintenance and Roadworthiness

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CONTENT

1. Overview

Safety and emission improvements are the main challenges for an increasing vehicle fleet in developing countries. While Government can set standards for safe, clean and fuel efficient cars, only an efficient Inspection & Maintenance (I/M) scheme can maintain safety levels (*e.g.* brakes, lights, chassis) and low emissions (*e.g.* exhaust gas test, OBD check).

The following recommendations from a major workshop in Chongqing, China (*Strengthening Vehicle Inspection & Maintenance*, 7–9 November 2001, http://citiesact.org/cleanairinitiative/portal/node/2988) involving developing Asian countries summarise the main aspects of introducing an efficient inspection & maintenance (I/M) program:

- Governments should announce well in advance the schedule for tightening emissions standards for new vehicles (*e.g.* Euro 3, Euro 4), as well as introducing an I/M program.
- It is usually better to adopt standards that fail the worst 20–25 % of the vehicle fleet and to gradually tighten the standards as the service industry and maintenance practices improve.
- Centralised I/M systems, where the inspection function is separated from the maintenance function, have produced the best results with respect to efficiency and fraud.
- In defining the structure of an I/M system, there should be a careful and thorough dialogue among all relevant stakeholders, especially national government, regional public authorities and their assisting organisations.
- Effectiveness of voluntary programs is limited, as the vehicle owner is expected to pay for vehicle inspection. There is a need for a legal I/M framework from national government and regional public authorities.
- I/M systems should ideally be regulated within a national framework.
- With regard to the repair sector, vehicle manufacturers can play an important role in providing training.
- The most important factors for the success of I/M are support by senior decision makers and the institutional capacity to manage and regulate the system.

2. Introduction

Market-based instruments in controlling vehicle emissions should incorporate the "polluter-pays" principle to provide incentives to reduce air pollution. Differential taxes and other incentives should encourage owners and operators of vehicles to use vehicles which pollute the least. They should encourage use of the cleanest fuel and regular vehicle maintenance. However, in addition to such incentives, there is also a need for enforcement measures which communicate the "polluter-pays" message to all drivers.

To improve air quality by technical measures, effective emission reduction strategies for road transport are needed. For policy-makers, one of the main challenges in air pollution abatement in the traffic sector is replacing old, high emitting vehicle technologies with new, low emitting ones. Short and mid-term strategies therefore should focus on:

1. *Fuel quality standards*;
2. *Retrofit programs for old vehicles*;
3. *Inspection & maintenance for safety and emissions and roadworthiness tests for all vehicles.*

This module deals with Inspection & Maintenance and roadworthiness tests as a major component of an overall strategy of emission reduction from road transport. Especially in a situation where no or low fuel quality standards and emission limits are set for all modes of road transport, an effective I/M or roadworthiness system is one of the most cost-effective ways of improving both air quality and road safety. Vehicle inspection programs can improve maintenance levels for vehicles and bring about a higher turnover of vehicles as well. This is due to the fact that I/M focus on all vehicles currently in use in a vehicle fleet. I/M help ensure that all vehicle owners maintain their vehicles regularly, which in turn helps ensure that these vehicles comply with emission limits. Even though in a developing country context, the specific emission limits of the vehicles in an I/M program could be high compared to a new car, I/M leads to emission reductions which would not be possible if the vehicles were not maintained and inspected at all (see Figure 1). A properly maintained vehicle has up to 7 % less fuel consumption –depending on the emission standard.

A note on terminology

- ***Roadworthiness*** refers to both ***inspection & maintenance*** and ***safety checks*** combined.
- ***Safety*** refers to non-emission related aspects such as brakes, lights and steering.
- ***Inspection & maintenance*** (I/M) refer to checks and repairs of pollutant emission related devices. It is recommended, however, to implement I/M together with safety checks.

I/M + Safety = Roadworthiness

Following common usage (but at the risk of some confusion!), in this module roadworthiness is often used interchangeably with I/M and I/M and roadworthiness.

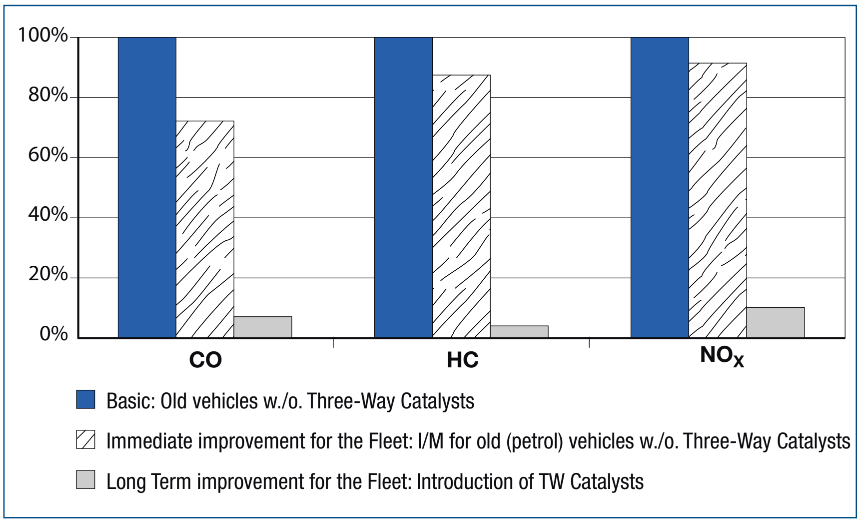

Fig. 1

Emission reductions possible through I/M, for vehicles without and with three-way catalysts. An I/M system focuses on rapid improvements in air pollutant reduction for the whole vehicle fleet.

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A simple I/M approach for safe and clean cars should consist of the following main steps, which are explained in detail in the following pages:

- Governments should restrict their main responsibilities to determining the overall approach toward:
  - emission limits,
  - definition of the I/M inspection requirements for safety and emissions,
  - supervision of the technical service;
- The technical service (technical inspection company or agency) should have long-term experience with I/M in other countries; countries can benefit from technical cooperation projects with international organisations (*e.g.* TUV SUD, DEKRA, US Organisations);
- The technical service should be the winner of an independent and open tender procedure and be responsible for the performance of the inspections under government supervision.

Fig. 2

Surabaya, Indonesia. Policy-makers should take a targeted approach to inspection regulations in terms of pollutants and vehicle types.

Reinhard Kolke, April 2001

Roadworthiness testing is one of the best ways to improve road safety in developing cities. I/M improves emissions and fuel consumption through a visual test and simple emission measurements or OBD check in a short time frame for the whole vehicle fleet, additional to a safety check (*e.g.* brakes, lights).

"Roadworthiness testing is one of the best ways to improve road safety and emissions in developing cities."

2.1 General requirements for I/M

In developing cities, a small number of vehicles often cause a large percentage of air pollution or are responsible for accidents caused by technical failures. To ensure the enforcement of an effective I/M system, it should focus especially on vehicle types which can be identified as gross polluters or unsafe cars. Targeted I/M programs can substantially improve safety and reduce pollution.

Therefore, depending on fleet characteristics, it is possible that one country concentrates on I/M and roadworthiness tests for buses and commercial heavy-duty vehicles, while another initially concentrates on I/M for motorcycles. An overall approach will be the most effective scheme. Therefore, I/M should include heavy duty trucks, buses, commercial passenger cars, private passenger cars, scooter and motorcycles.

An inspection system should combine I/M emission checks with safety checks, together summarised as a roadworthiness test. The checks are a combination of simple visual checks and tests made by computer-aided machines.

"An inspection system should combine I/M emission checks with safety checks, which is called roadworthiness test."

I/M systems should ideally be regulated within a national framework. Several countries have opted to delegate the responsibility for implementing I/M systems to the local government. This is feasible if the local implementation takes place within the context of a national regulatory

Regulatory requirements

The main step is the establishment of legal and regulatory requirements, as a basis for the implementation of an effective system. Regulatory requirements extend to:

Vehicle environment protection
- Exhaust emissions (I/M)
- Oil loss reduction
- Noise emissions
- Others

Vehicle safety and reliability
- Steering system
- Brake system
- Wheels & tyres
- Lighting system
- Gear & transmission system
- Chassis & body
- Others

framework. Therefore, the legal requirements and I/M principles should be defined and implemented on a national level, while the enforcement and definition of detailed procedures can be part of the local government's responsibility.

Fuel standards, as discussed in Module 4a: *Cleaner Fuels and Vehicle Technologies* are as important as emission standards and I/M requirements and they should be considered in parallel with any I/M policy.

2.2 State of the art and challenges

In some developing countries or cities, annual or bi-annual inspection systems are established for commercial vehicles only. Although these systems are sometimes highly ineffective, they do have some minor positive aspects as these "established systems" provide useful potential infrastructure for centralised test facilities. The negative aspect of many of theses systems is that the current tests at these facilities are sometimes performed badly or not at all. This can be due to defective and poorly maintained test equipment, lack of safeguards against fraud and corruption, as well as test mechanics that do not know how to use test equipment due to inadequate training.

A major problem which must be identified and solved in many developing cities is rampant fraud and corruption in current systems. Only effective measures against this can ensure that everyone trusts the enforced system. Such measures are outlined in this module.

2.3 Centralised vs decentralised I/M

Often the implementation of a decentralised I/M test system might appear initially to be an attractive option for policy-makers in developing cities. Tests and repairs (*i.e.* both Inspection & Maintenance) are both performed in private garages and at private dealer sites, which benefit from the new inspection and repair business. Proponents of such systems often state that through a decentralised system the government can save money on infrastructure investments.

But test-and-repair stations have a range of disadvantages for all stakeholders:
- There is no single standard in such decentralised systems for testing devices and

Three-way catalytic converters

A catalytic converter makes exhaust fumes less harmful. It is incorporated in the exhaust system of a motor vehicle. In a TWC emissions of hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x) are oxidized or reduced into their harmless elements of carbon dioxide, nitrogen and water vapour.

Centralised facilities are available…

Reinhard Kolke

…but suffer from defective equipment and poor performance

Reinhard Kolke

Fig. 3 and 4

Established test facilities and test performances in Surabaya, Indonesia.

diagnostic ability. In Germany, for example, the inspection requirement for the same car can differ at different test facilities, which can use different test equipment.

- There are differences in the training ("diagnostic abilities") of mechanics.
- Studies show that a decentralised I/M is less (or not at all) effective in emission reduction compared to a centralised system.
- Inspection in decentralised garages causes much higher costs for the vehicle owner than would be the case at a centralised, test-only facility. The conflict of interest between inspection on the one side and the repair business on the other often leads to unnecessary repairs and so to higher costs.
- High prices for equipment that is not used regularly in decentralised garages must be considered.
- There is a lack of a centralised database and information system.
- There is a lack of acceptance by the community due to a lack of trust in inspection results from workshops.

"The members of the Asian Development Bank Workshop 2001 in Chongqing concluded that decentralised test-and-repair systems have been much less successful than test-only, single contractor-run I/M systems. Test-and-repair systems are very difficult to supervise and audit and have been found to be more vulnerable to corruption."

A centralised system consisting of test-only-stations plus the existing repair garages for maintenance purposes, on the other hand, has many benefits:

- Centralised inspection allows government to implement I/M in the most effective, simplest manner.
- Centralised I/M is less prone to corruption.
- Centralised I/M reduces investment costs, especially if one contractor carries out the inspection at test-only-stations.
- Centralised I/M offers new business and job opportunities for local repair workshops for maintenance work.

Even the so-called "centralised I/M procedure" is not completely centralised. There is still a need for "decentralised" maintenance and repairs in workshops, which need more time than the time- and cost-efficient roadworthiness inspection lane in a centralised test facility.

Fig. 5

Centralised, test-only systems work best

Centralised I/M and roadworthiness test systems or so called test-only stations, whereby inspection is separate from maintenance works –which can be performed by garages and dealer– works best. Even in a centralised system, contractors from the private sector are best qualified to implement centralised I/M and roadworthiness systems, which must be regulated by the government.

Reinhard Kolke

3. I/M and roadworthiness regulation and tendering

Legislation should regulate the following:

- Definition of the inspection & maintenance requirements for motor vehicles;
- Licensing and control of private sector vehicle testing stations;
- Qualifications of testing personnel;
- Characteristics and equipment of the testing stations;
- Vehicle testing fees;
- Documentation;
- Cases of withdrawal of both station and personnel licensing;
- Enforcement of roadside tests;
- Penalties for breach of licensing conditions (stations, personnel).

Two critical factors for success of I/M are *support by senior policy-makers* and the *institutional capacity to manage and regulate the system*. These are often weak in developing cities and, as a consequence, a weak regulatory framework results. Inadequate funding and weak enforcement frequently leads to a system that is plagued by corruption and poor quality control. In general, tender procedures and test performances by private contractors are state-of-the-art in South and East European Countries (*e.g.* Lithuania, Greece), in States of the United States (*e.g.* Massachusetts, Colorado) and in Latin America (*e.g.* Mexico, Chile).

3.1 Potential for Government revenues: I/M by private sector and tender procedure

Experience around the world has demonstrated that while governments should regulate I/M programs, the implementation of such programs can best be carried out by the private sector.

The major objective of the tender is to implement and enforce roadworthiness legislation to ensure low emissions and improve fuel efficiency as well as increase safety and reliability. One possible introduction strategy can be the introduction of requirements similar to EC Directive 2009/40/EC (see http://eur-lex.europa.eu) related to Inspection & Maintenance procedures and roadworthiness tests for motor vehicles.

The national government should introduce the legal requirements, while regional governments can follow the tender procedure to identify private contractors and enforce the I/M procedure.

The test procedure has to be efficient for all kind of vehicles, including motorcycles, vehicles without catalytic converters, as well as vehicles with three-way catalytic converters and diesel cars. Additional requirements will be set for safety and reliability.

A simple safety and reliability check for motorcycles is needed, as their share of the vehicle fleet may be high, especially throughout Asia.

The combination of a charge to pay for the emission and safety certificate and a sticker with the test fee (see Section 4.7) for the standardised roadworthiness test, guarantees the Government income for additional development funding. This income is only possible if roadworthiness is implemented in a centralised system with test-only stations, with only one responsible contracting company.

If the strategy of introducing a simple "I/M module" and a simple "safety and reliability module" on a centralised basis, including all legal requirements and tender procedures is followed, making detailed changes to a particular module becomes a simple matter because the infrastructure is already set and easily to be changed by the government.

One attractive possibility is for the Government to provide land for test facilities to a contractor at no cost, to reduce the overhead costs for the test facilities. This will in turn allow lower roadworthiness test fees.

In Kolke (2001), the cost of I/M procedures were roughly calculated for Indonesia: an annual test fee (commercial vehicles) and/or bi-annual test fee (*e.g.* private vehicles or vehicles with low emissions) of USD 10 to USD 15 should be sufficient under consideration of both today's willingness to pay, and of test costs of approximately USD 5. A tender procedure should consider these rough amounts to get a proposal from an interested contractor. The bidders for the contract have to provide a proposal, which may include the possibility of offering a rate for the roadworthiness service.

"This [government] income is only possible if roadworthiness is implemented in a centralised system with test-only stations, with one responsible contracting company."

The introduction of safety tests for motorcycles has the potential to increase safety, reduce accidents and significantly increase public revenues. Therefore, the tender procedure should consider particular types of motorised vehicles and the composition of the vehicle fleet including motorcycles. New test procedures for noise tests for motorcycles should also be considered (see Section 6.4). For the tender procedure and the identification of a contractor, a technical tender draft as well as a formal tender draft, are required. The formal tender draft will specify the procedure to be followed.

The only useful I/M system is a centralised one, with regulatory responsibilities borne by the government. A private contractor, as the winner of a tender process, should carry out the roadworthiness testing procedure. This will result in reduced costs and a more effective I/M system.

3.2 Roadside I/M tests

To ensure that vehicle owners do not tamper with emission or safety related parts of their vehicles after they have passed an I/M and roadworthiness procedure, the legislation should consider random roadside vehicle inspections. Roadside vehicle inspections should be carried out at random by the contractor, in order to avoid misunderstandings. The contractor for roadworthiness tests must be different from the contractor for road-side inspections because of a possible conflict of interest. Moreover, road-side inspection could be carried out also by governmental organisations to get more information and know-how on vehicle inspection.

The financing of these additional tests with support of the police must be considered in the calculations of the amount of the test fees required. It is recommended that it should be proven that a number of up to 10 % of the vehicles tested every year are tested by roadside vehicles inspections, to help ensure that all vehicle owners carry out the tests.

Roadside programs are difficult to oversee and supervise and are more open to corruption than I/M in fixed stations. Roadside testing, however, can complement a more comprehensive I/M system. Roadside testing helps ensure that all vehicles comply with the safety standard and I/M requirements at all times (see Section 8).

Fig. 6 and 7
Roadside test performance.
Bureau of Automotive Repair

4. Technical requirements and standards

When a technical inspection system is introduced, the general condition of the vehicles in use must be taken into account. As a rule, this means that the requirements for the vehicle inspection must initially be kept to a minimum.

The inspection must nevertheless ensure that the emissions and the most important safety-related parts of the vehicle (*e.g.* brakes, steering and lights) are covered. The standard of the inspection can then be raised at a later date without modifying the inspection system in order to reach the intended international standard.

Specifications as summarised in the following paragraphs must ensure that the introduction of I/M and roadworthiness will meet the goals of emission reduction, environmental and safety requirements. A modular system can be extended step by step to meet the requirements of changes in fuel and automotive technologies, and for additional environmental requirements.

4.1 Number and dimension of inspection facilities

Centralised vehicle inspection stations are the best solution for periodical vehicle inspections. The size and number of inspection lanes required at such facilities will be based mainly on the volume of inspections expected, but also on the following factors:

- Inspection intervals for different vehicle types;
- Number of inspections per lane and per day;
- Experience of staff;
- Analysis of the vehicle stock;
- Technical condition and age of the vehicles;
- Number of working days per year;
- Growth rate for the vehicle fleet to be tested;
- Failure rate and re-tests.

Once the average number of required test facilities is determined, additional factors for identifying suitable test facilities include:

- Size of sites available;
- Possibility of noise from vehicles tested;
- Road network in the area of the planned sites;
- Access for heavy duty vehicles;
- Location should not be in residential areas;
- Connection to district arterial road network;
- Accessibility for the customers;
- Availability of electricity, water, etc.

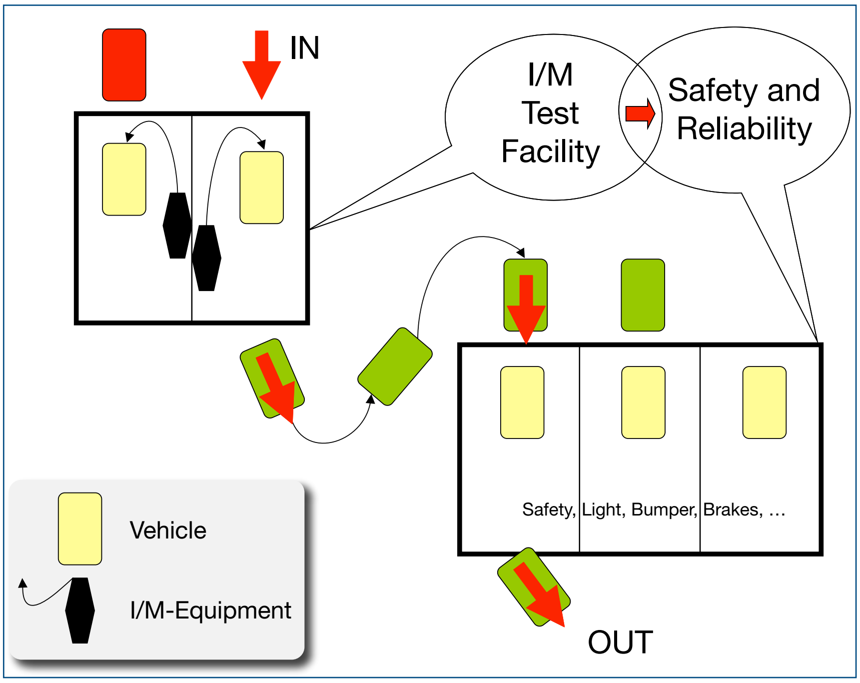

Fig. 8
Structure of an I/M and safety test facility.
Reinhard Kolke

4.2 Automatic vs manual inspection

The design of an inspection facility depends on the size, equipment and number of vehicles that must be accommodated.

In general, the whole roadworthiness and emission test procedure should be automatically controlled by a computer. The inspector should not have the possibility to change to manual modes

Fig. 9
A modular emissions testing centre in Germany.
Reinhard Kolke, 2001

for passing a vehicle through the inspection. Therefore, an effective I/M needs fully automated pass/fail decisions.

Automatic control can reduce fraud and corruption significantly, even though more expensive inspection instruments and computer systems, including the necessary software are required. The climatic conditions (temperature, humidity, etc.) should be taken into account. A "semi-automatic" system including some "automatic" aspects, such as a semi-automatic brake test, a computer-based database and a wholly automatic storage of data and printing of certificates will be the best solution for many developing countries.

Based on experience of technical services in Europe, the following staff minimum requirements for stationary single-lane facilities are:

- 1 station manager;
- 3 technicians;
- 1 administrator.

4.3 Mobile inspection facility

In rural areas with small numbers of vehicles, there are two possibilities of dealing with vehicles which do not contribute significantly to overall pollution or safety problems. The first possibility is to exempt these vehicles in rural areas, which should be considered in developing countries. Another possibility is the use of a mobile test facility.

A mobile test facility is only suitable if the costs for each test would not be higher than for a test in a centralised system.

Another possibility is to use appropriate workshops and carry out the tests in the presence of an authorised inspector. This may be a solution if the rural areas are not easily accessible (*e.g.* bad road conditions or lack of acceptable road connections).

Fig. 10
A mobile test facility in Germany.
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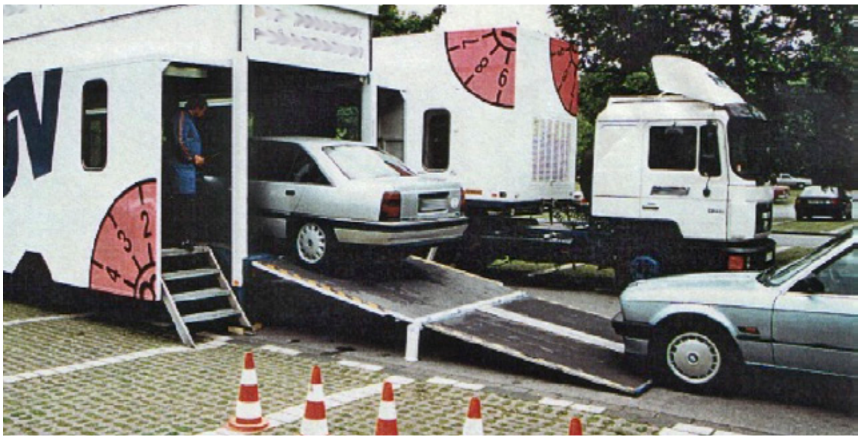


4.4 I/M contractor and staff training

A joint venture of national or international approved contractors with local staff or with a local contractor can enforce legal regulations in a short time frame. The international or national approved contractor must be responsible for all aspects of planning, construction with local partners and operation of the local inspection facility. If an international contractor is part of the I/M and roadworthiness contract, its main duty is the operation of the inspection facilities with appropriately trained local staff.

The contractor has to be responsible for the inspection of all kinds of vehicles, including:

Standard Inspection	One single standard inspection procedure for all vehicles of a region
Equal Treatment	Equal treatment of all customers by standard application of the regulation
Uniform Staff Training	Uniform standard of staff training for the different jobs required
Quality and Safety	Attainment of a uniform quality and safety level
Uniform Data Use	Uniform data acquisition and data processing to provide statistics for emission control and traffic safety
Adjustment of Inspection Standard	Continuous uniform adjustment of the inspection standard to changing requirements, vehicle fleets and fuel standards

The contractor has to offer regular training for the emission test and safety test to guarantee that the trainees will become specialists in their field. On the other hand, the trained specialists also need a general view of the structure of motor vehicle inspection. This must enable them to understand the principles within which they are working and enable them to convey to the customers the benefits of inspection and maintenance of motor vehicles.

Each trainee must be required to pass an examination at the end of the training lessons in order to demonstrate sufficient knowledge and practice, which is required for recognition as an expert in vehicle testing.

The trainee should receive a *carné* showing that he has passed the tests. He has to carry this *carné* always and present it to governmental inspectors if required.

4.5 Roadworthiness test performance

Each I/M procedure starts with the identification of the vehicle data. ***Vehicle identification data*** consists of:

- License plate number;
- Vehicle manufacturer;
- Vehicle type;
- Vehicle identification number if available (in many countries this number does not exist, especially in older vehicles);
- Vehicle mileage.

The test can be divided into two main modules. The first module is the emissions check; the second is the safety check. Each module consists of two steps: a visual check and a measurement test, using computer-aided test equipment.

Emissions (environmental) test

A computerised system reduces emission test manipulation, because data cannot be submitted manually to the computer-printed certificate.

Visual environmental checks

The visual environmental check consists of:

- Oil losses;
- Exhaust system.

The visual inspection ensures that:

- There are no leaks at the exhaust system;
- There are no leaks at the oil system;
- If applicable, the emissions control system is present.

Measured environmental tests

Measured environmental tests are of:

- Exhaust smoke (diesel engines);
- Exhaust CO/HC/Lambda (petrol engines);
- CO_2 (to avoid manipulation and to ensure that the exhaust system has no leaks);
- Noise.

"The test can be divided into two main modules. The first module is the emissions check; the second is the safety check."

The exhaust-gas measuring module operates in conjunction with a computer unit. The module has no control or display elements. This is part of the computer unit. It is able to measure CO, CO_2, HC and O_2 and then calculates the lambda value *cf.* petrol engines. The measured values are then transmitted to the PC module via a serial interface.

The Opacimeter records the exhaust opacity of diesel engines. It will be brought to the exhaust for exhaust gas measurement. The procedure

Emission test performance

Reinhard Kolke

Fig. 11
Computerised test

Fig. 12
Visual check

consists of allowing the exhaust gases, via the sampling probe and sampling hose, to enter the measuring chamber under their own pressure, *i.e.* without vacuum assistance. The opacity will then be measured in accordance with the absorption procedure. The absorption coefficient will be determined from the light absorption (degree of opacity in %) in accordance with the so-called Beer Lambert law. The opacity measuring equipment is connected to the computer unit via an adapter lead.

Safety checks

The second module, the safety checks, is also a combination of visual checks and necessary measurements. Both modules combined –emissions and road safety– and enforced by trained, responsible personnel, allow an effective roadworthiness test.

Visual Safety Checks	
Registration Plate and Vehicle Identification Number	
Rear Lamps and Registration Plate Lamps	
Mechanical Brake Hand Lever	
Windscreen Wipers and Washers/Ventilation	
Seats	Service Brake Pedal
Horn	Service Brake testing
Glass	Auxiliary Lamp Condition
Rear View Mirrors	Steering Wheel Play
Safety Belts	Door/Locks/Anti-Theft Devices
Stop Lamps	Towing Bracket/Coupling
Side Lamps	Indicators/Tell Tales
Reflector	Headlamp Condition
Speedometer	Bumpers
	Running Boards and Steps
Measured Safety Tests	
Front Wheel Side Slip and Rear Wheel Side Slip	
Front and Rear Axle Suspension	
Service Brake Performance	
Service Brake Imbalance	
Parking Brake Performance	
Parking Brake Imbalance	
Headlamp Aim	Auxiliary Lamp Aim

The headlight-centring device has a robust structure with illumination meter and is floor-rail-mounted for ease of use. It is equipped with precision lux meter, mirror viewfinder and glass lens.

The modular vehicle acceptance system is used for testing the brakes, the wheel suspension and the wheel alignment (side-slip). The configuration can be adjusted to the specific interests and investment options of the service centre. It is possible to conduct an automatic test sequence. One operator can do the whole test. It is customer-friendly with graphical representation of the tests and measurement results.

The wheel suspension tester obtains the road contact value and the particularly important maximum differential between the right and left side of the wheel for road holding. Additional assessment aids display the theoretical

Safety test performance

Reinhard Kolke

Fig. 13
Visual check

Fig. 14
Measurement test (light check)

road contact value and measure the damping coefficient. The road contact value is the smallest wheel contact force which occurs during the test procedure.

The brake dynamometer measures the braking-force characteristic dependent on pedal force or time, rolling resistance, ovalisation and braking-force differential. The test roller set is a one-piece unit and floor-levelled.

If I/M and roadworthiness are introduced for the first time, the emission and safety module can be reduced in a first phase to a useful minimum. This means that, first of all, the main test procedures should be performed. This could be the inspection of brakes, lights, running boards for safety and oil losses, and CO and opacity under unloaded conditions (acceleration with transmission in neutral) for environmental checks.

4.6 Cost of test equipment

The cost of the equipment varies according to the specifications. If the government follows a tender procedure, which results in a contract, equipment cost will not be of main concern for the government. These numbers must be calculated by the contractors case by case for their bidding. The results will depend on several differing boundary conditions.

The cost per test is much dependent on parameters additional to the test equipment cost, such as cost for the facility sites, construction, staff acquisition and training. While costs for inspection sites depend on local cost for land and could be reduced if government provides public ground or test facilities, cost for human resources depends on regional levels of payment.

Fig. 15

A range of test equipment from one manufacturer.

BOSCH

4.7 Required data for I/M

In many developing countries, existing databases are inadequate. Reliable data is needed. This includes data on the characteristics of the existing vehicle fleet such as number of vehicles, age, types of engines and emissions that should be registered in a central computerised database. The centralised database should be adapted with the up-to-date test data of I/M and roadworthiness inspections.

An effective I/M and roadworthiness system should be linked to an effective periodical (usually annually) registration system to ensure compliance. Another link is needed to an official I/M and roadworthiness certificate, where only the staff of the official contractor is

I/M plates and stickers

Fig. 16

Simple screw; simple manipulation.

Reinhard Kolke

Fig. 17

Unremovable sticker; manipulation impossible.

Reinhard Kolke

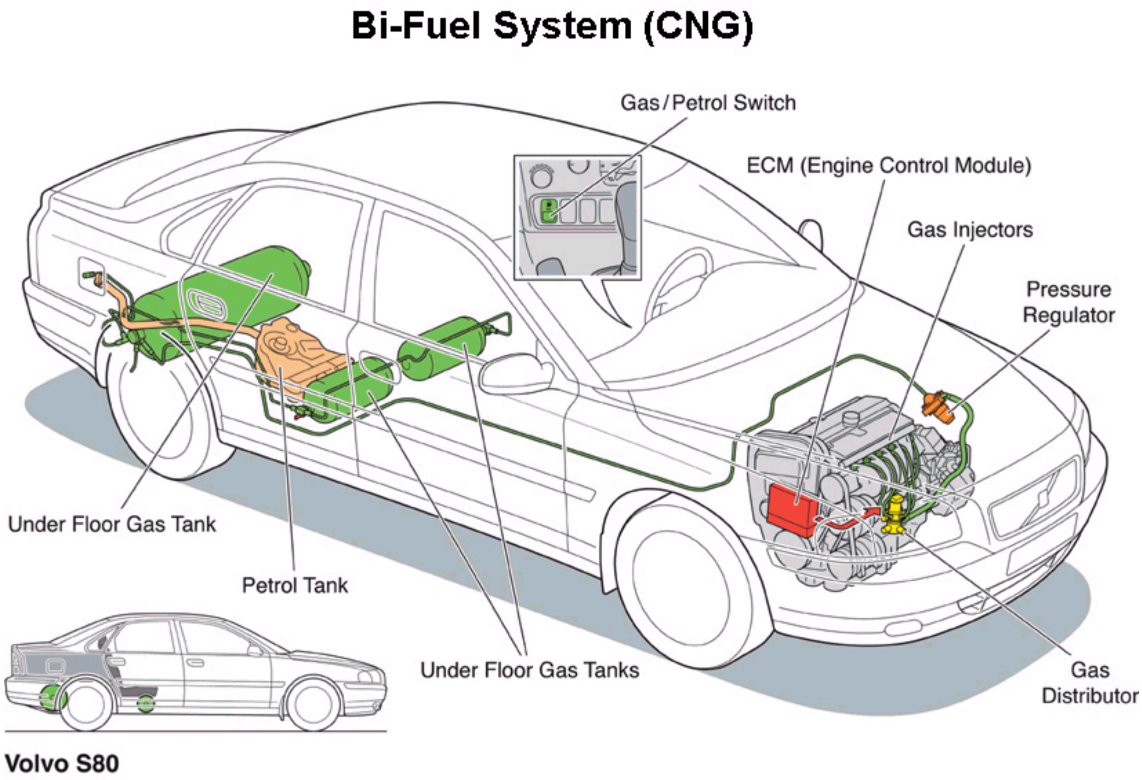


Fig. 18
CNG bi-fuel system.
Volvo

allowed to sign and where the staff is responsible for that, including consequences in cases of manipulation.

To reduce the danger of fraud and corruption, some basic data items need to be registered during the inspection (compare Section 4.5).

> ***"Computerisation of certification, I/M and roadworthiness is an effective way to alleviate the problems of fraud and corruption."***

This data normally includes vehicle and owner related items such as:

Vehicle:
- license plate number
- make and model
- year of first registration
- chassis identification number
- engine identification number
- vehicle identification number
- exhaust emission control system (with or without cat and lambda sensor)

Owner:
- name
- address

This data, including the I/M and roadworthiness certificate with a *pass decision*, should be required for the periodical registration. Computerisation of certification, I/M and roadworthiness is an effective way to alleviate the problems of fraud and corruption. This has for example been the experience in Mexico City.

4.8 Inspections of gas vehicles

The emissions and safety tests for Compressed Natural Gas (CNG) vehicles as well as Liquefied Petroleum Gas (LPG) vehicles are similar to vehicles with petrol engines. For safety tests of gas vehicles, additional safety checks of gas systems are necessary. If the vehicle is equipped with an additional CNG or LPG system as well as with a petrol system (bivalent system) the emission test should be done for both types of fuel used.

4.9 Setting I/M procedures and standards

There are three main approaches to standards setting: European, American and Japanese. Most countries in the Asian region have tended toward the European standards for new cars and trucks, relying in large parts on the UN Economic Commission for Europe (ECE) (see Table 1). With regard to 2 and 3-wheeled vehicles,

Table 1: Emission standards for new light-duty vehicles

http://citiesact.org/cleanairinitiative/portal/system/files/documents/17_roadmap_to_cleaner_fuels_and_vehicles_in_asia.pdf, accessed 13 May 2011

Country	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
EU	E 1	Euro 2					Euro 3				Euro 4			Euro 5					Euro 6					
HK, PRC	Euro 1		Euro 2				Euro 3					Euro 4			Euro 5									
South Korea												Euro 4			Euro 5									
PRC[a]						Euro 1				Euro 2			Euro 3			Euro 4								
PRC[e]					Euro 1			Euro 2			Euro 3			Euro 4				Euro 5						
Taipei, China					US Tier 1									US Tier 2 Bin 7[f]										
Singapore[a]	Euro 1						Euro 2																	
Singapore[b]	Euro 1						Euro 2					Euro 4												
India[c]							Euro 1				Euro 2					Euro 3								
India[d]					E 1	Euro 2					Euro 3					Euro 4								
Thailand	Euro 1						Euro 2			Euro 3								Euro 4						
Malaysia			Euro 1												Euro 2				Euro 4					
Philippines									Euro 1				Euro 2								Euro 4			
Vientnam													Euro 2											E 4
Indonesia											Euro 2													
Bangladesh[a]											Euro 2													
Bangladesh[b]											Euro 1													
Pakistan															Euro 2[a]		Euro 2[b]							
Sri Lanka									Euro 1															
Nepal						Euro 1																		

Notes:

*The level of adoption vary by country but most are based on the Euro emission standards;

a) – Petrol; b) – Diesel; c) – Entire country;

d) – Delhi, Mumbai, Kolkata, Chennai, Hyderabad, Bangalore, Lucknow, Kanpur, Agra, Surat, Ahmedabad, Pune and Sholapur; Other cities in India are in Euro 2;

e) – Beijing [Euro 1 (Jan 1999); Euro 2 (Aug 2002); Euro 3 (2005); Euro 4 (1 Mar 2008); Euro 5 (2012)], Shanghai [Euro 1 (2000); Euro 2 (Mar 2003); Euro 3 (2007); Euro 4 (2010)] and Guangzhou [Euro 1 (Jan 2000); Euro 2 (Jul 2004); Euro 3 (Sep-Oct 2006); Euro 4 (2010)];

f) – Equivalent to Euro 4 emissions standards

Source: CAI-Asia. June 2010. Emission standards for new light-duty vehicles

however, the standards adopted by India, Thailand, Taipei and China are seen as the most advanced. Tightening of new vehicle emission standards should be followed by a concomitant tightening of in-use I/M standards for these newer model vehicles.

Setting the I/M standards must consist of two steps. The first step is the identification and definition of the test procedures; the second step is the definition of emission test standards.

I/M test procedures

I/M test procedures can be divided into three different areas (see Figure 19). The simplest way to perform an I/M test is an unloaded short test (*e.g.* idle at 800 rpm or high idle emission test at 2,500/2,800 rpm). Low cost per test is an advantage of that test procedure but problems arising due to low cost effectiveness are a drawback. In particular, when a vehicle fails the I/M test, even though having low overall emissions, it can cause high costs. But the test procedure must also be good enough that vehicles with high emissions

Fig. 19
I/M Test Procedures.

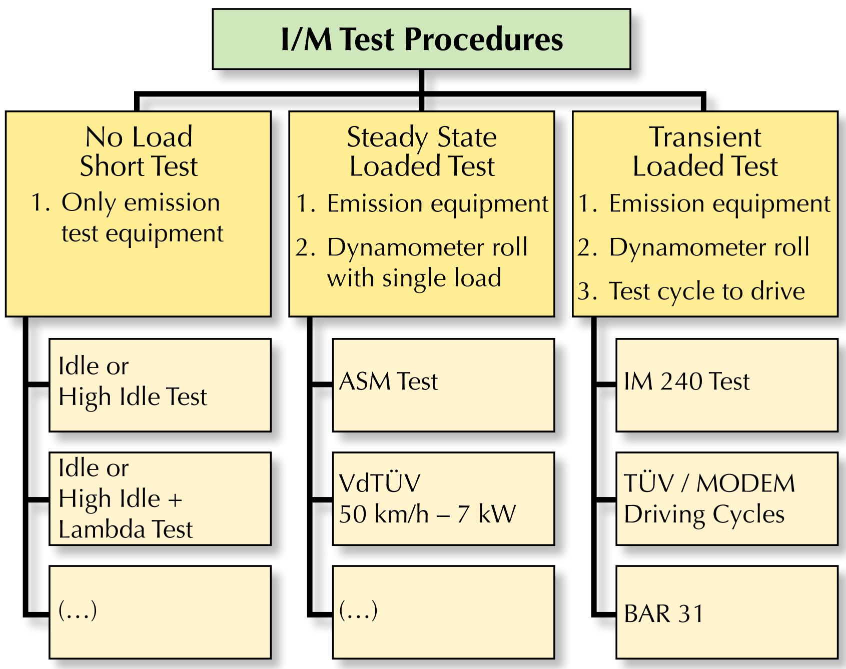


Table 2: Emission standards for in-use vehicles in Asia

These in-use standards should form the basis for routine vehicle inspections carried out as part of the Inspection & Maintenance program or for roadside apprehension program.

Courtesy of Asian Development Bank, Policy Guidelines to Reduce Vehicle Emissions in Asia: Vehicle Emission Standards and Inspection & Maintenance, as seen by July 2005 under: http://www.cleanairnet.org/caiasia/1412/article-58969.html

Diesel			
Country	**Effectivity date**	**Smoke HSU**	**Test**
Bangladesh	—	65	—
Cambodia	Current	50	—
Hong Kong, China	Current	60	Free acceleration
		50	Loaded lug down test on a chassis dynamometer[a]
India	Current	65	Free acceleration
Indonesia	Current	50	Free acceleration
Malaysia	Current	50	—
Nepal[b]	Current	65	—
Pakistan	Current	40	Free acceleration
Philippines	Current	2.5 m^{-1}	Free acceleration[c]
Philippines	2003	2.5 m^{-1}	Free acceleration[d]
PRC	Current	4.5 Rb	Free acceleration
Singapore	Current	50	—
Sri Lanka	Current	65	Idle
Sri Lanka	Current	75	Free acceleration
Thailand	Current	45	Free acceleration
Thailand	Current	35	Loaded
Thailand	Current	50	Filter test – free acceleration
Thailand	Current	40	Filter test – loaded
Viet Nam[e]	Current	72	Idle
Viet Nam[f]	Current	85	Idle
Viet Nam[g]	2005	72	Idle

a for vehicles apprehended under the Smoky Vehicle Control Program;
b for vehicles manufactured in 1995 and beyond;
c For naturally aspirated engines; limit is 2.5 m^{-1} for turbo-charged engine and 4.5 m^{-1} for a 1,000 m increase in elevation;
d For naturally aspirated engines; limit is 2.2 m^{-1} for turbo-charged engine and 3.2 m^{-1} for a 1,000 m increase in elevation;
e Applicable in Hanoi, Ho Chi Minh, Hai Phong, Da Nang;
f Rest of country;
g Limit is 50 HSU for newly registered vehicles starting 2005;
HSU = Hartridge smoke unit;
m^{-1} = light absorption coefficient;
Rb = Filter or Bosch smoke meter unit.

Petrol				
Country	**Effectivity date**	**CO %**	**HC ppm**	**Test**
Bangladesh	—	24.0 g/km	2.0 g/km	Dynamic
Cambodia	Current	4.5	10,000	Idle
Hong Kong	Current	0.5	—	Low idle or in accordance with manufacturers' specifications
		0.3	—	High idle, I = 1±0.03 or in accordance with manufacturers' specifications
India	Current	3.0		Idle
Indonesia	Current	4.5	1,200	Idle
Malaysia	Current	3.5–4.5	600–800	Idle
Nepal	Current	3.0	1,000	—
Pakistan	Current	6.0	—	Idle
Philippines	Before 1997 January	4.5	800	Idle
Philippines	1997	3.5	600	Idle
Philippines	2003	4.5	800	Idle
PRC[a]	Current	4.5	900	Idle
PRC[b]	Current	4.5	1,200	Idle
Singapore	Current	3.6–6.0	—	Idle
Sri Lanka	Before 1998	4.5	1,200	Low idling
Sri Lanka	After 1998	3.0	1,200	Low idling
Thailand	Before 1993 November	4.5	600	Idle
Thailand	After 1993 November	1.5	200	Idle
Viet Nam[c]	Proposed 2002 December	6.0[d]	1,500	Idle
Viet Nam[c]	Proposed 2005	4.5[e]	1,200	Idle
Viet Nam[c]	Proposed 2008	3.0[f]	600	Idle

a for light duty vehicles;
b for heavy duty vehicles;
c Applicable in Hanoi, Ho Chi Minh, Hai Phong, Da Nang;
d Rest of country CO limit = 6.5%;
e Rest of country CO limit = 6.0%;
f Rest of country CO limit = 4.5%;
CO = carbon monoxide;
g/km = gram per kilometre;
HC = hydrocarbons;
ppm = parts per million.

in reality cannot pass the I/M test because of the low efficiency of the test procedure.

Idle and free acceleration testing is appropriate for pre-Euro 1 standard vehicles to control emissions, but loaded tests are more effective for Euro 1 compliant vehicles. Idle testing can be a useful indicator of gross polluters in all vehicle categories up to a Euro 2 standard. For all other vehicles a test under load, performed on a dynamometer roll, should be used. The best option is a transient load test, which includes a driving curve on the dynamometer roll.

I/M emission standards

Table 2 lists I/M emission limits applicable in a range of Asian countries. In general, setting standards can result in two problematic situations:

1. *Standards are set too stringently and most vehicles fail, placing a great strain on the service sector, the capacity of the inspection program, vehicle owners, as well as being politically unacceptable (error of commission).*
2. *Standards are set too loosely which results in little benefit from the program and flagging public support (error of omission).*

I/M limits for petrol vehicles

For petrol cars, a leading indicator of emissions performance is carbon monoxide (CO). Any I/M test should be based mainly on a CO test and can be extended by additional analysis (*e.g.* to HC). For conventional petrol cars, a limit reduction from 3.5 % v/v to 1.5 % v/v is possible.

An initial I/M emission limit for CO at idle is sufficient for petrol vehicles without catalytic converters. The limit should be set at a value of 3.5 % v/v (1.5 % v/v) in the short term. Emission limits for petrol vehicles with catalytic converters should be set to 0.5 % v/v at idle (see Table 3).

I/M limits for diesel vehicles

Highly polluting diesel vehicles emit large amounts of particulates under high load conditions (*e.g.* accelerating after stop). The main test procedure used for an I/M short test is the measurement of opacity at free acceleration. In that case, the engine is accelerated with transmission in neutral (no load) from idle up to maximum (governor cut-off) speed and the smoke opacity is measured. This simple unloaded test may identify gross polluters, but is associated with many errors for cars that fail I/M but do not have high emissions in real life (error of commission). Additionally, there is no correlation between this test and any other transient or loaded test.

Further requirements are necessary for diesel vehicles in the I/M regulations, to specify preconditions and test performances.

For the introduction of diesel I/M, the poor efficiency of the free acceleration test should be considered. Even though it is well known that a continuous opacity measurement over a short transient cycle is found to be promising when smoke is visible, there are not many examples available from other countries having already implemented these procedures on a broad basis.

Some countries and cities are leading the way with respect to testing of certain types of vehicles such as the Smoky Vehicle Control Program in Hong Kong, which involves dynamometer smoke testing for light and heavy duty diesel vehicles.

Table 3: I/M emission limits in the European Union for petrol vehicles

Vehicle description	Idle CO v/v	High idle CO[1] v/v
Conventional Petrol Cars Manufactured before 10/1986	4.5 %	–
Conventional Petrol Cars Manufactured after 10/1986	3.5 %	–
All Models with 3-way catalyst and lambda control from Euro 3 Petrol Cars	0.5 % 0.3 %	0.3 % 0.2 %

1) Test to be conducted at a minimum idle speed of 2,000. Lambda: 1 ± 0.03.

Table 4: I/M emission limits in the European Union for diesel vehicles

Vehicle description	Opacity [1]
All Diesel Vehicles:	Type approval limits + tolerance of 0.5 m^{-1}
Alternatively	
Naturally aspired Diesel engines (Diesel w./o. turbo)	2.5 m^{-1}
Turbo-charged Diesel engines (Diesel with turbo)	3.0 m^{-1}
Euro 4 Diesel engines	1.5 m^{-1}

1) Maximum coefficient of light absorption as defined for a free acceleration smoke test

Hong Kong's Smoky Vehicle Program

Hong Kong's Environmental Protection Department (EPD) has a long-standing program to spot smoky vehicles and more than 64,000 smoky vehicle reports were handled in 2000.

The vehicles must pass a smoke test within two weeks of being spotted. Police are among the trained spotters and they can hand out fixed penalty tickets, which in 2000 increased from USD 450–1,000. The police and EPD's Local Control Offices work together to step up enforcement against smoky vehicles (EPD 2001 courtesy of Kong Ha; for more information see http://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/cleaning_air_atroad.html).

Even though an initial I/M emission limit for opacity at free acceleration seems to be sufficient for diesel vehicles, the procedure of "free acceleration" has more drawbacks than advantages (see Table 4).

The limit for the maximum coefficient of light absorption should be set to the manufacturer value. Alternately, they were set to 2.0 m^{-1}. Further attention must be drawn to precondition procedures and test performance (limitation of acceleration time, etc.).

4.10 Frequency of testing

The specification of test periods for the different vehicle categories is often of great interest to policy-makers. A simple rule is that the higher the annual vehicle mileage performed by a vehicle category, the shorter the inspection interval should be. In practice it can mean: annual tests for buses, commercial heavy duty and light duty vehicles, but bi-annual tests for private cars and motorcycles (see Table 5).

Another question to address refers to the ages of vehicles at which emission testing should initially start and the frequency of tests to follow. The main strategy should be an annual emission test for all vehicles without catalytic converter and additionally for all vehicles with high annual vehicle mileage (*e.g.* buses, heavy duty vehicles, taxis). These "high mileage vehicles" should be tested for safety on an annual basis as well. The only vehicle types to test bi-annually for safety are privately owned passenger cars. Similar test frequencies are performed in other countries (*e.g.* member states of the European Union, States in the USA). Table 6 summarises the recommended test frequencies for developing countries; also applicable to other countries.

Table 5: Suggested frequency of vehicles to be tested

Annual test	Bi-annual test
■ Buses ■ Heavy goods vehicles ■ Taxis ■ Rental cars (without driver) ■ Driving school cars ■ Motorcycles and other vehicle types rented to the public ■ Commercial vehicles; *e.g.* vans, light goods vehicles ■ Old private vehicles; *e.g.* beyond 25 years	■ Private cars (with up to 8 seats plus the driver) ■ Motorcycles and other vehicle types (excluding those rented to the public)

"A simple rule is that the higher the annual vehicle mileage performed by a vehicle category, the shorter the inspection interval should be."

Motorcycles should also be tested on a regular basis, to reduce emissions and to reduce the number of accidents caused by missing safety requirements (*e.g.* brakes, steering, tyres).

Table 6: Frequency of road worthiness tests (all figures are in months)

Vehicle Type	Initial Test for New Vehicles	Emission Tests	Safety Tests [1]
Vehicles without three-way catalytic converter			
Vehicles without catalytic converter	24	12	24
Passenger cars for public transport (taxi, bus)	12	12	12
Others	24	12	12
Vehicles with Diesel Engines up to 3.5 t gross weight			
Passenger Cars	36	24	24
Passenger cars for public use (taxi, bus, rent)	12	12	12
Others	24	12	12
Vehicles with Diesel Engines of more than 3.5 t gross weight			
All Vehicles (buses, heavy duty vehicles)	12	12	12
Vehicles with 3-way catalytic converter			
Passenger Cars	36	24	24
Passenger cars for public use (taxi, bus, rent)	12	12	12
Others	24	12	12
Motorcycles			
Motorcycles with 2-stroke engine	24	2)	24
Motorcycles with 4-stroke engine	24	12	24
Motorcycles with 4-stroke engine, 3-way catalyst and lambda control	24	24	24

1) Safety test should include visual test (leakage, etc.)
2) Appropriate test equipment is not available

5. Inspection & maintenance system case studies*

* By Frank Dursbeck, International Consultant Traffic and Environment, Germany

5.1 Santiago de Chile

An emission control system for motor vehicles comprises several parts, including: vehicle type approval, periodical vehicle inspection and road-side inspection (Figure 20). Such a system today is nearly fully implemented in the metropolitan region of Santiago de Chile.

Vehicle type approval

In 1992, the first regulations with respect to exhaust gas emissions from light duty vehicles (EPA 83 regulations) and later also for heavy duty trucks and buses (Euro 1 regulations) came into force in Chile. At the same time the *Centro de Control y Certificación Vehicular* was designed and constructed to carry out exhaust gas type approval tests for new vehicle types (Figure 21).

Fig. 21
Exhaust emission laboratory, Centro de Control y Certificación Vehicular. This facility carries out type approval testing for new vehicles.
Frank Dursbeck

Actually trucks and buses have to fulfil the Euro 3 regulations with respect to CO, HC and NO_X emissions. The urban buses additionally have to be equipped with a diesel particulate filter to comply with the Euro 4 standards for particulate emissions.

Light duty vehicles have to fulfil the European standards set fourth in the regulation 98/69 EC.

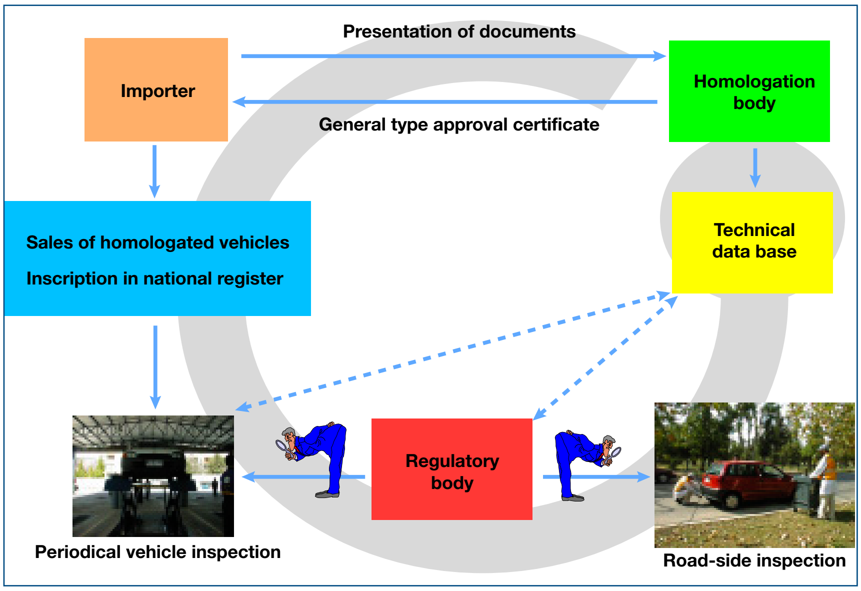


Fig. 20
Integrated vehicle emission control system.
Frank Dursbeck

This centre today is, along with the CETESB laboratories in Sao Paulo, the only manufacturer-independent institution in South America carrying out exhaust gas emission tests according to national and international standards.

Periodical vehicle inspection

The first vehicle inspection regimes were introduced in Chile in 1977, but due to various reasons –too many concessions, lack of quality control of the inspection stations, and so on– the controls were not very effective.

In 1994, the new technical inspection system was implemented. This inspection system had 4 private operators and a total of 25 automated inspection stations –2 for urban and interurban buses, 4 for taxis, school buses and heavy duty trucks and 19 for passenger cars (Figure 22). The vehicles are inspected for safety aspects as well as for exhaust gas emissions. For light duty vehicles, the emission control is carried out at

Fig. 22
Periodical exhaust emission control in Santiago de Chile.
Frank Dursbeck

idle and high idle, with different standards for conventional vehicles and vehicles with three-way catalytic converters.

Since 1 September 2008 the exhaust gas control test for vehicles with catalytic converter was changed from the pure idle emission control to the ASM test (Acceleration Simulation Mode). With this test not only the CO and HC emissions are controlled but also the NO_X-emissions. By this, a more effective control of the efficiency of the catalytic converters has been implemented. Chile is the only South American country that has introduced this test method.

For buses, the opacity is measured not only at free acceleration -the most common form of test worldwide- but also at full load and maximum torque revolutions per minute (rpm) (Figure 23). This effective control system for diesel vehicles has only been introduced in Chile.

Fig. 23
Periodical exhaust emission control of buses at full load on a chassis dynamometer.
Frank Dursbeck

To carry out an effective quality control, the *Departamento de Fiscalización* carries out daily inspection of all the plants. In this manner, manipulation is reduced to an acceptable minimum.

Road-side inspection

It is well known that, especially in developing countries, vehicles are often especially prepared to pass the vehicle inspection system tests. Afterwards, changes are made to the pre-inspection status. To avoid this manipulation, a road-side inspection system for the Metropolitan Region of Santiago de Chile was designed and implemented in 1993. Vehicles are stopped on the road and tested for exhaust gas emissions (Figure 24 and 25). Initially, nearly 30 % of the tested buses failed. Today, the failure rate has fallen to about 10 %. This control system, together with vehicle type approvals and periodical inspections, contributes to reducing air pollution from motor vehicles, and makes it possible to avoid manipulation and corruption.

Results

For more than 10 years, the Chilean authorities under coordination of the National Environmental Commission for the Metropolitan Region of Santiago de Chile (CONAMA RM) fought the air pollution problem. Many of the measures taken were supported by GIZ. The various measures taken have contributed to the decreasing particulate concentrations in the ambient air of Santiago de Chile (see Table 7).

Further measures

However, although many measures have been successfully implemented, the mobile sector is still responsible for nearly 40 % of the overall air pollution. Clearly, more measures have to

Fig. 24 and 25
Road-side inspection of buses.
Frank Dursbeck

Table 7: Annual change in pollutant concentrations in the metropolitan region of Santiago de Chile (1997–2007)

Pollutant	Status quo	Unit	Year 1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
MP_{10} annual	50	µg/m³	97	96	80	77	71	70	75	68	66	72	70
MP_{10} 24 h P98	150	µg/m³	317	282	269	250	229	234	219	188	183	218	233
Ozon 8 h P99	120	µg/m³	201	207	181	195	189	197	182	168	176	172	–
NO_2 1 h P99	400	µg/m³	236	272	276	268	306	350	320	279	229	261	–
NO_2 annual	100	µg/m³	41	51	35	38	45	48	53	50	36	41	–
CO 1 h P99	30	mg/m³	29	23	20	19	16	20	16	14	12	12	–
CO 8 h P99	10	mg/m³	18	14	14	13	11	14	12	11	9	9	–
SO_2 annual	80	µg/m³	18	16	13	10	10	9	9	8	9	10	–
SO_2 24 h P99	250	µg/m³	108	80	67	47	55	33	40	35	34	37	–

Source: Seremi de Salud RM-Conama (2008)
http://www.leychile.cl/Navegar?idNorma=1012499&idVersion=2010-04-16, accessed 7 June 2011

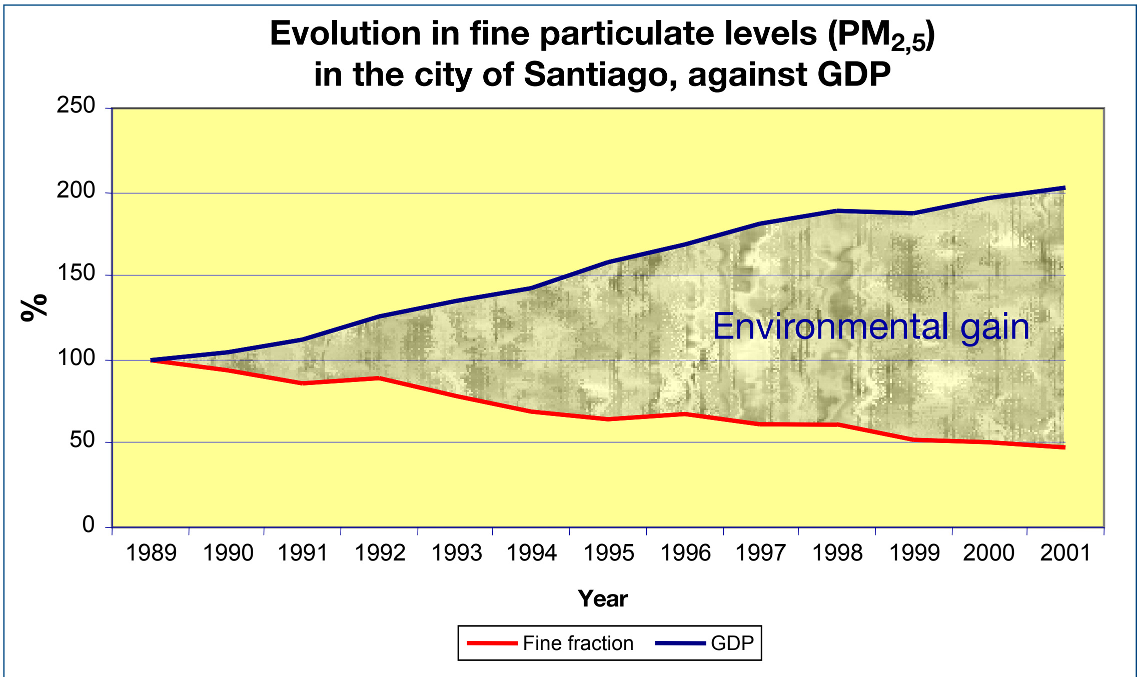


Fig. 26
Economic growth and trends in fine particulate levels in Santiago de Chile.
CONAMA RM

be taken to reduce the air pollution by vehicles. The exhaust gas standards will be more stringent. The public transport system has been improved significantly but inspection and maintenance still need improvement.

5.2 The new vehicle inspection system in Costa Rica

For many years, the authorities in Costa Rica have been discussing the nationwide introduction of an integrated vehicle inspection system. The background of these discussions was the perception that the maintenance status of the vehicles on the road was not acceptable from both a safety and environmental perspective. As a first step the so-called *Ecomarchamo*, a decentralised exhaust emission control system, was introduced, but for several reasons it had only a limited success.

Various efforts were carried out to launch calls for tenders for a new vehicle inspection system, including exhaust emission control and safety inspection of all vehicles, with close assistance from the local GIZ experts. After difficulties and delays during the advertisement and contracting phase, the periodic vehicle inspection system recently commenced country-wide. The new system can serve as a good example.

Country-wide coverage with a total of 13 inspection stations with 38 test lanes (see Figure 27) results in acceptable driving distances for the vehicle owners to reach testing stations. The appearance (see Figure 28) of the inspection station demonstrates seriousness and technical competence.

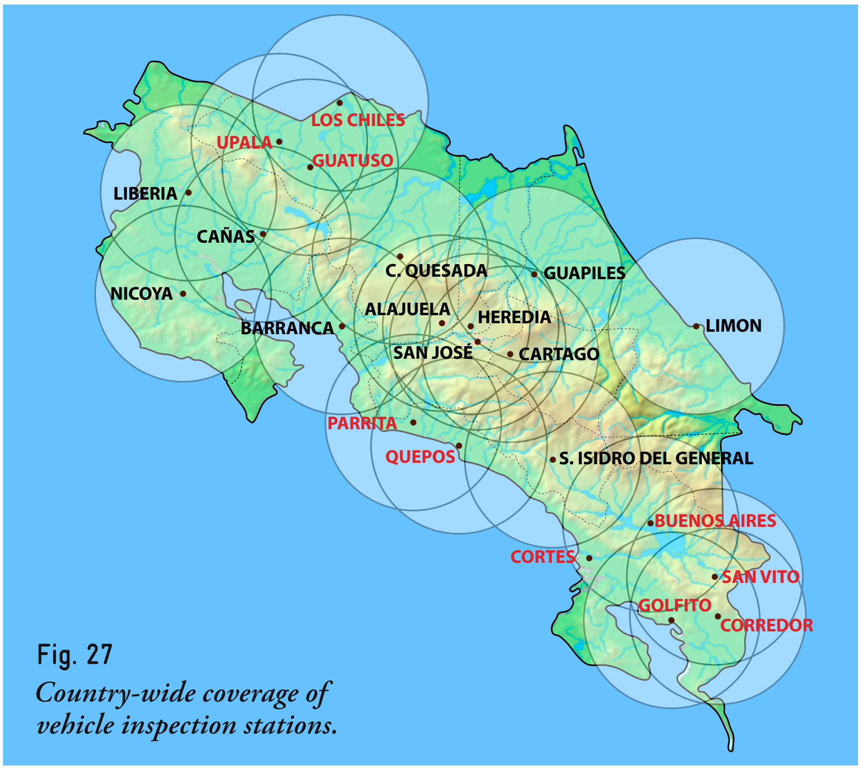


Fig. 27
Country-wide coverage of vehicle inspection stations.

In addition to the periodical vehicle inspection, a so-called road-side inspection system will be introduced shortly, in order to guarantee the success of the technical inspection and to avoid manipulations of the vehicles after they have passed the technical inspection.

Further action is still needed. The roadworthiness and emissions performance of imported new and used vehicles is inadequately regulated. An effective vehicle type approval system is needed, based on international standards. The emission standards in the periodical exhaust emission testing have to be revised continuously and adjusted to technical developments. Moreover, in regard to air pollution control, the vehicle emission testing is important but only a first step in the right direction. It is necessary to develop an integrated air pollution control plan which addresses all sources of air pollution.

Fig. 28
Test station with six inspection lanes in Heredia.

6. I/M requirements and testing of motorcycles*

* This section was reviewed by N. V. Iyer of Bajaj Auto Ltd, who also provided additional notes included in the text.

6.1 Introduction

Motorcycles should also be tested on a regular basis to improve the average safety standards and to reduce the number of accidents caused by missing safety requirements (*e.g.* brakes, steering, tyres) (see Figure 29).

Fig. 29
Motorcycle emission testing.
RWTÜV

Idle and free acceleration testing is appropriate for introducing I/M for motorcycles to control emissions, but loaded tests are more effective (see Figure 30a and 30b).

Fig. 30a, 30b
Catalytic exhaust controls for motorcycles are the most cost-effective way to meet stringent emission standards.
SWR

Two-wheel vehicles using two-stroke engines emit substantial quantities of hydrocarbons (HC), carbon monoxide (CO) and particulate matter. These pollutants have significant adverse health effects and result in deteriorating environmental quality. The contribution to urban air pollution, where these vehicles are in use, has become an increasingly common phenomenon. This is especially noticed in densely populated areas of the world, such as in most Asian countries, which rely on two-wheel vehicles as an essential means of transportation.

Motorcycles should comply with the same safety and environmental requirements as passenger cars. Unfortunately, requirements for emission tests for motorcycles are still under discussion in some countries because pollution from cars was higher on the agenda in recent years and some specific problems must be faced when testing emissions of two-stroke engine two-wheelers.

Two-stroke engines use high proportions of lubricating oil, usually up to 2 % of the fuel. Unlike in the four-stroke engine, which has an oil sump, the lubricating oil in the two-stroke engine is introduced along with the air-fuel mixture. Since this does not get combusted in the engine completely, most of it is emitted through the exhaust. This unburned oil can heavily soil or even destroy the measuring equipment. Therefore, hydrocarbon from oil must be trapped in front of the emission measurement cell to protect the measurement equipment. The shapes, exit angles and sizes of the exhaust tail pipes of two-wheelers vary a great deal from model to model due to technical, packaging and aesthetic considerations. Therefore, it is difficult to provide the connecting equipment for all types of motorcycles. For that reason, the I/M concept for motorcycles can have some more practical problems (*e.g.* to have ready access to the right connector between tailpipe and measurement device for a variety of motorcycle tailpipe configurations), which are possible to solve, but of which governments should nonetheless be aware.

Another area of great concern is noise emissions from motorcycles, which in several developing cities predominate over all other vehicle categories. Therefore, a noise test for motorcycles should be seriously considered.

"Idle and free acceleration testing is appropriate for introducing I/M for motorcycles to control emissions, but loaded tests are more effective."

6.2 Controlling motorcycle pollution

The critical elements of a successful pollution control program for two-wheel vehicles have emerged from the growing experience gained by countries, which have implemented effective programs. Taiwan, for example, has implemented three phases of emission standards since 1992 with increasing strictness (see Figure 31). India is another country that has enforced progressively strict emission standards for two- and three-wheelers.

Fig. 31
Taipei has been a leading city in applying strict emission standards for motorcycles.
Gerhard Metschies

Catalytic exhaust controls have been developed as a result of these regulations and are generally recognised to be the most cost-effective way to meet stringent emission standards for two-stroke engines. The catalytic converters are mostly of the open loop oxidative type since there is a need to control only CO and HC of two-stroke engines; the NO_X emissions of these engines being inherently extremely low. In some cases, in addition or independently, secondary air injection is employed. Thus, fully developed and proven emission control systems are readily available. Key elements for reducing emissions from two- and three-wheelers are discussed in detail in Module 4c: *Two- and Three-Wheelers*. These include (MECA, 1999):

1. *Establish firm regulations with specific emission control performance requirements or "standards" and a duration period during which the vehicle must meet these standards (e.g. 15,000 km).*
2. *Establish a specific test procedure, representative of actual two-wheel vehicle driving conditions in actual operation, under which two-wheel manufacturers must demonstrate compliance with the emission standards.*
3. *Require a certification compliance process to demonstrate that the vehicle will meet the applicable standards for the required duration and/or time period.*
4. *Implement a vehicle inspection program to ensure that vehicle emissions in use are meeting the required standards.*
5. *Develop a public education program to gain public support and to assure public understanding of the health benefits of low polluting two-wheel vehicles, the importance of good vehicle maintenance, and of using proper fuels and lubricating oils.*

6.3 Emissions and safety tests for motorcycles

I/M for motorcycles are not performed in many countries, although some countries in the Asian region such as Taiwan, Thailand and India have introduced in-use emission inspection for motorcycles. I/M should be considered for motorcycles as well as for all other vehicle types (see Section 2.1). The following aspects of an I/M system for motorcycles were discussed in a German research project funded by the German Federal Environmental Agency. The German emission limits for motorcycles –introduced in 2006– are described in Table 8.

In addition to a visual environmental and safety check, the tester should determine the following test data:

- Engine temperature (°C);
- Idle number of revolutions (min/max) [min^{-1}];
- CO-emission at idle [% v/v];
- High idle number of revolutions (if required*) (min/max) [min^{-1}];
- CO-emission at high idle (if required*) [% v/v];
- Lambda-sensor test (if required*).

* For four-stroke engines with 3-way catalyst and lambda control only.

Due to strong pulsations and turbulences in the exhaust of motorcycles, the following specifications must be considered when emissions are measured. If emissions are measured directly at the muffler the exhaust is mixed with the ambient air, which distorts the results.

Therefore, the end of the exhaust system needs a close-fitting extension pipe to ensure that the emission measurement sensor must be inserted with a minimum distance of 60 cm into the exhaust system. Back pressure should not exceed more than 125 mm water column. The proportion of the extension pipe should further not dilute the exhaust, nor interfere the operation of the motorcycle. If the engine has more than one exhaust systems in parallel, the extension pipe must confluence the exhaust from both systems into one pipe. Alternatively the CO-measurement can be performed in each exhaust system separately. The result is the arithmetic average of each measurement.

The risk of sample dilution has been found to be an extremely important issue in case of motorcycles in India. Whilst all efforts are made to prevent dilution, there is a provision to make a correction for the dilution by simultaneously measuring CO_2, in addition to CO and HC. In fact, the trend is to go in for a four-gas analyser that includes measurement of CO, HC, CO_2 and O_2. Certain limits are used by the inspection centres for the maximum O_2 content in the exhaust to determine whether the test result is valid or not. In case of engines that use secondary air injection, the O_2 limit is determined using manufacturers' data of the amount of air injection.

While testing motorcycles with four-stroke engine, 3-way catalyst and lambda control –and all motorcycles two-stroke and four-stroke– that use oxidative catalytic converters, the test personnel must ensure that not only the engine has the engine temperature as required, but also the catalytic converter is heated as required. The open space construction of motorcycles supports a fast cooling of the catalyst after a short period of time. In that case, the efficiency of catalytic converters drops dramatically, which influences the results negatively.

Table 8: German I/M emission limits for motorcycles

Vehicle Description	Idle CO	High idle CO[1)]
Motorcycles with 2-stroke engine	Oil-removal filter required, but see note below	
Motorcycles with 4-stroke engine	4.5 % v/v	–
Motorcycles with 4-stroke engine, 3-way catalyst and lambda control	–	0.3 % v/v

1) Test to be conducted at an idle speed of 2,000–3,000 rpm. Lambda: 1 ± 0.03.

Note: It is both possible and required to have idle emission limits for two-stroke engine motorcycles. The limits for Idle CO in Taiwan and India for in-use vehicles are 4.5 % for both two-stroke and four-stroke engines. In addition, Taiwan has an Idle HC limit of 9,000 ppm. It must be noted that this HC is derived from unburned fuel and not lubricating oil. A similar HC limit is also being considered in India. These limits will be progressively tightened in the forthcoming regulations in both countries. In most of the Asian countries, the use of four-stroke engines with 3-way catalytic converter and lambda control is not prevalent for small motorcycles. Most of the four-stroke engine motorcycles in these countries at best use oxidative catalytic converters or secondary air injection, or both in a combination.

6.4 Noise tests for motorcycles

Noise emissions from motorcycles are a major environmental concern. Motorcycles are the vehicles category with the loudest noise emissions, especially relative to the vehicles' size. The behaviour of motorbike and motorcycle drivers sometimes also causes annoyance. Extreme acceleration as well as driving in low gears, high number of revolutions and acceleration to high idle speed causes high noise levels. Another problem is the use of illegal noise-inducing mufflers, which not only cause higher noise levels but cause a different "sound" as well, which increases annoyance again.

Facing the goal of annoyance reduction, it must be anticipated that manipulated and illegal exhaust systems and mufflers for motorcycles will be used in practice but changed to the regular muffler for I/M purposes only.

Due to high costs of noise emission measurements under loaded conditions (see Figure 32), the following compromise is proposed: a so-called "survey" method for a measurement as described in ISO 5130 can be used for a noise emission test. The ISO 5130 test is done in a

Aspects of noise

The noise value dB(A) is commonly used to describe the noise level. As it is logarithmic scale, a reduction of 3 dB(A) is similar to a 50 % reduction of the perceived noise (*e.g.* noise of one motorcycle instead of two motorcycles).

Please refer to Module 5c: *Noise and its Abatement* for more detailed information.

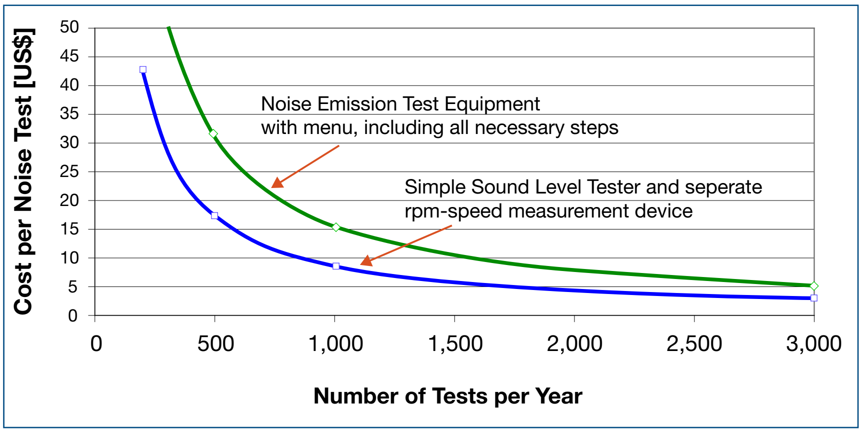


Fig. 32
Noise test cost varies according to equipment costs and the number of tests per year.

stationary condition of the vehicle and there is no running or distance covered.

Until such time as a new dynamic short test, as for example developed and proposed by the German Federal Environmental Agency, gets well established, the current practice of obtaining a 'signature' of the initial stationary noise level at the time of Type Approval, and checking the in-use vehicle against that level represents a practical alternative for developing countries.

Although motorcycle manufacturers have historically resisted efforts to solve the noise problem, this situation may now be changing. The pass-by noise standards for motorcycles in Europe, Japan and many other countries are getting tighter and tighter. Achieving compliance to these stringent levels is no longer possible only by muffler design changes but require design improvements in the basic engine structure and the vehicle. Such vehicles would obviously also be less vulnerable to user tampering.

Test area requirements

Any open space or site can be used for noise emission tests, if no significant and additional noise source is located nearby. A level ground of hard consistency is required to ensure a high sound reflection (*e.g.* asphalt, concrete, paving stones). The size of the site needs a minimum of 3 metres around the contour of the motorcycle. Closed rooms should not be used.

During the measurement, the surrounding noise interferences should have a minimum difference of 10 dB(A) below the noise to measure. During the measurement no persons or moveable objects are allowed in the 3 metre by 3 metre area. The micro is fixed on a tripod and needs a minimum distance to any barrier (kerb, steps, etc.) of 1 metre (see Figure 33).

The measurement equipment is a precision-sound-level measurement equipment (class 1), which is officially calibrated at time periods as required. The measurements must be tested –and aligned if necessary– with a calibrator before each measurement. The calibrator needs an official standardisation certificate.

The proposed noise test should be combined with the emission test (see Section 6.3).

Fig. 33
Sound level measuring installation.
Norsonic

7. Technical tools supporting I/M

Two additional technical means can support I/M systems to ensure their effectiveness: On-Board Diagnostics (OBD) and remote sensing. Both means, however, have important limitations. The following paragraphs will give a brief description and compare their advantages and disadvantages.

7.1 OBD for I/M

What is OBD?

On-Board Diagnostic (OBD) systems are included in most new cars and new light trucks. Since the early 1980's, manufacturers started using ODB as an electronic means to control engine functions and diagnose engine problems for vehicles manufactured and sold in Japan, USA and Europe. This was primarily to meet US EPA and similar European (Euro 1, etc.) and Japanese emission standards. Through the years, on-board diagnostic systems have become more sophisticated. US OBD-II or the European E-OBD, a new standard introduced in the mid-1990s (US) and late-1990s (Europe since Euro 3, 2000), provides almost complete engine control and also monitors parts of the chassis, body and accessory devices, as well as the diagnostic control network of the car. A set of monitoring strategies is incorporated into the on-board computer to detect component or system malfunctions.

Scan tools for OBD

The main idea introducing scan tools to read out On Board Diagnostic information is to reduce expenditure and time required for the inspection procedure using emission measurement equipment (see Figure 34a, 34b). Considering that OBD will work in practice in the same way, as it should in theory, each vehicle will inspect itself continuously. That means that there is only a need to check the OBD malfunction indicators every year or bi-annually to ensure that every private owner maintains his/her vehicle.

There are a growing number of scan tools compatible with 1996 and newer vehicles with a wide variety of features. In principle, the use of an OBD scan tool instead of any test procedure is less expensive and is simpler. The cost of the OBD scan tool will start at USD 80, if a handheld version for private use is required.

Fig. 34a, 34b
Major components of a remote sensing operation.
INRETS, TNO, TÜV [3]

OBD tools and I/M: pros and cons

The use of OBD technologies for I/M may reduce cost, inspection time, equipment needs and optimise technical requirements for I/M.

But there are a growing number of problems which developing countries will have to face if they decide to rely heavily on OBD.

Strengths and Weaknesses of ODB for I/M

- Reduced cost, time and equipment needed;
- ODB should identify gross emitters;
- OBD only monitors exceedances of the OBD thresholds, which may be considerably higher than the emission limits at which the vehicles were once certified (*e.g.* emission limits of Euro 3, 4);
- The OBD-system has to test itself regularly and set a "readiness code" which determines that the exhaust system has no malfunctions or that malfunctions are recorded. If the readiness code is not set, an emission test must be performed.

The combination of OBD and I/M is often touted as a cost effective tool to perform I/M on new vehicle generations. The truth is that theory and realities for OBD diverge significantly, for many reasons. It would not be advisable for developing countries to implement OBD in an I/M program without any loaded or transient test on a dynamometer test bench.

It is possible to equip the I/M test devices with an additional scan tool easily, which allows reading out the OBD codes and using them additionally to the I/M data from emission tests.

7.2 Remote sensing for I/M

What is remote sensing?

An optical remote sensor is conventionally set up to transmit a beam of radiation across a parcel of air to be investigated (see Figure 35). This involves the sitting of a transmitter, normally a radiation source, at one location and a receiver at another. The path between these two points defines the optical path.

Remote sensing: pros and cons

Remote sensing has a number of advantages over conventional tests:

- It can measure the emissions from a very large number of vehicles.
- Measurement can be made without any inconvenience to the vehicle driver.
- Automated system would allow measurement to be made with little manpower effort.

There are however several problems with the application of remote sensing:

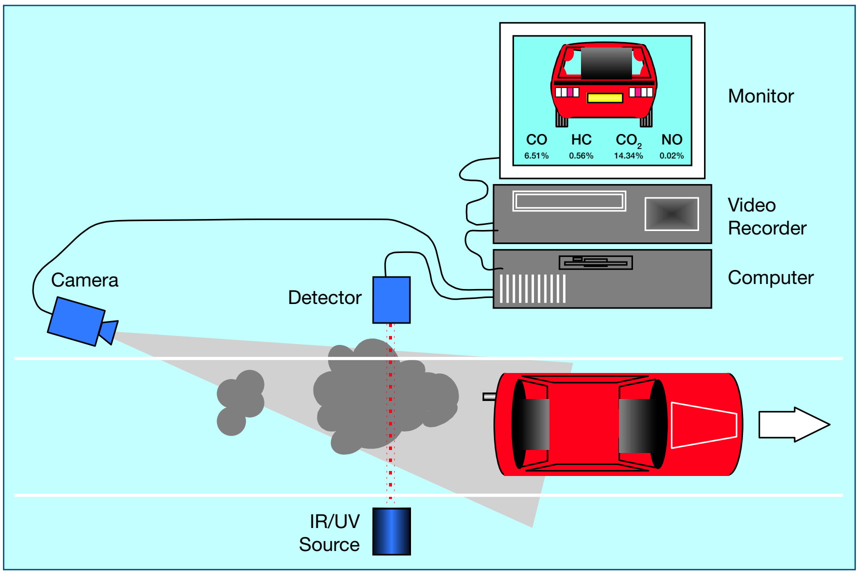
- There is a variation in a vehicle's exhaust emissions with driving parameters (road layout, load, etc.). Previous studies, based on fleets comprising almost entirely of non-catalyst vehicles, have identified this problem as rendering remote sensing ineffective.
- Detecting vehicles with CO emissions just over the emissions limits means that a large number of vehicles fail the remote test which would not fail a complex type approval test (error of commission).

It should also be noted that the remote sensing tests were carried out in countries which already have an established I/M test procedure.

Fig. 35

A novel enforcement measure against smoky vehicles.

http://adb.org/vehicle-emissions



Strengths of remote sensing

Strengths of remote sensing include:

- Simple and cheap test for high numbers of vehicles and identification of gross emitters.
- Transient emissions tests do not reflect real world conditions as good as remote sensing.
- Measurements under load are possible while testing on (freeway) ramps (1–3 % slope required).
- Correlation of remote sensing and homologation tests is possible, when data of average emissions of vehicle age classes are used.
- If vehicles, which failed the I/M test are sold or registered outside the I/M area, remote sensing may identify these on the streets.
- Calculation of an average emission factor for huge fleets possible.

Weaknesses of remote sensing

However, remote sensing has many weaknesses:

- "One second drive by" measurements cannot be made under representative and repeatable road conditions as with a loaded I/M test.
- Safety concerns for tests on road side (cars sometimes crash into test devices).
- Data use of one emission factor under load with different acceleration and stop conditions is problematic and not representative.
- Developers of the system often state that they would have a good correlation between "vehicle ages" and emissions. But these "vehicle age classes" do not reflect the emissions of single vehicles, which are required for I/M.
- Emission factor for fleets does not represent real world emission from the variety of specific vehicle types, driving conditions and other boundary conditions.

- Correlations between repeatable loaded or transient tests and Remote Sensing are poor.

At the moment, remote sensing is used to increase public awareness in the field of vehicle pollution. A vehicle owner who passes a remote sensor and a sign, which classifies the emission measurement as “GOOD”, “FAIR” or “POOR”, should check the “manufacturers recommendations about how to keep the car healthy and our air clean” in cases where the measurement indicates a “POOR” (see Figure 36a and 36b).

Fig. 36a, 36b


CABQ


Aircarecolorado

Currently, the only interesting application of remote sensing is as a rough screening of emissions for vehicles under one very specific, unrepeatable driving condition. Cost and maintenance requirements for the whole routine outweigh the theoretical benefits of remote sensing, though from a scientific point of view, remote sensing offers many interesting research fields.

Smoky vehicles reported via SMS

The Asian Development Bank’s Vehicle Emission Reductions Website reported in July 2002 that Filipinos can now report smoke-belching vehicles to the Land Transportation Office (LTO) using the text messaging feature of their cell phones.

To send a text message, they simply key in “USOK <space> plate number <space> location sighted <space> vehicle description” and send it to “2366” (see Figure 37). If a vehicle is reported at least five times, the LTO will require the owner to bring in his vehicle for emission testing.

Update: The Far Eastern Economic Review reported that since early June, the program has netted more than 30,000 text messages with 1,000 smoke-belching vehicles liable. There have been 400 summonses sent with 120 turning out to be wrongly addressed. All in all, only 12 vehicle owners responded and only two cars have been taken off the road.

FEER, 18-Jul-02, from
http://adb.org/vehicle-emissions

Fig. 37
An example of a network configuration for an ‘online’ I/M database.
BOSCH

8. Quality assurance

I/M programs have often been associated with fraud and corruption. Failure to address these issues will seriously or even totally compromise the effectiveness of I/M systems in reducing emissions. Experience shows that corruption can be effectively controlled at reasonable costs in test-only networks. Test-and-repair networks still suffer from fraud and corruption problems even with intensive quality assurance efforts. A well functioning audit and quality assurance system –difficult to achieve with a test-and-repair system– is crucial for the acceptance and success of any I/M system.

Fines, control and verification structure

A legal basis for fines and other sanctions is required to attract any company from the private sector to run an effective I/M program. If private companies make large investments to get a contract, they must be able to rely on the fact that vehicles are tested for roadworthiness and I/M on a regular basis and that it is no more attractive to pay a low fine or to get a manipulated certificate through bribery. The definition of fines and sanctions must be part of the regulation. With regard to fines and sanctions the following strategies should also be considered.

Fully automated pass/fail decision

As a general rule, the less reliance there is on human judgment or manual actions, the more reliable the result. The test and quality control systems should be fully automated and a computer-based automatic exhaust measurement should make the pass/fail decision for the overall results and for those tests which are performed by machines and computers. These automatic systems are most notably the emission test systems, while most safety checks are part of the visual-manual-checks, which sometimes cannot be performed automatically. The whole safety and environmental I/M check is therefore semi-automatic.

Punishing corrupt inspectors

A key element of a successful I/M program is how to enforce rules against corrupt entities, especially inspectors. Attention should be given to establishing appropriate sanctions and effective legal procedures to assure that a workable system is in place.

Roadside tests

A useful example is the introduction of roadside tests to examine vehicles if they are tested regularly (*e.g.* testing a number of 10 % of the annual tested vehicles at roadside vehicle inspection tests). This ensures that vehicles are not only "clean for a day", tuned to pass the test and then immediately readjusted causing high pollutions afterwards (see Section 3.2).

Combination of annual vehicle registration and I/M

Vehicle registration should be combined with the mandatory requirement of a passed roadworthiness test. One problem may be that not all vehicle types are registered in the same way and at the same official agency (*e.g.* bus registration compared to motorcycle registration).

Revocation of vehicle license

The revocation of the vehicle's license should be mandatory, if a vehicle owner has not carried out a roadworthiness test on his/her car.

External I/M auditing group

In the early stages of introducing an I/M program, it is recommended that an independent international expert group supports a tender process as well as the introduction of the I/M. The members of this expert group should have extensive experience with roadworthiness procedures. The expert group should review the tender procedure and audit the process of roadworthiness after a defined period of introduction (*e.g.* after one, two years). Results of these audits should be made public.

Contractor runs I/M auditing group

Although in a system run by a private contractor, the contractor is also responsible for preventing fraud and needs to have its own audit system for this purpose, this does not replace the independent audit program implemented by or outsourced to a separate contractor by the government. Results of these audits should be made public.

Powers and duties of the regulatory agency

The duties of the regulatory agency are often not well defined and the agency is usually not well staffed in many developing countries. The duties of the regulatory agency should include design of the I/M system, setting appropriate test procedures and standards, assuring proper operation of the I/M program and rigorous auditing. Where audits identify problems, the regulatory agency should be authorised and have the capacity to enforce the requirements, including embargo of testing, the removal of the license to carry out the inspection by offending operators and stations, and the imposition of monetary penalties.

Data management system

A well functioning I/M system will include a data management system that ensures that all test data are collected automatically and manipulation of input data is impossible. All test data are transmitted on a regular basis to a central database. This will be easier if computers that transmit information on a real-time basis link centralised I/M stations (see Figure 38).

Such data exchange has been standard practice in many developing and developed countries for years. A data management system is much easier to use and maintain in a system with uniform equipment and a limited number of contractors.

Equipment and station maintenance

Some I/M systems, especially those operated directly by government staff using government-owned equipment and stations, lack the technical capability, sufficient staff and adequate funds to assure that software and hardware are maintained, calibrated, used and upgraded appropriately. In the absence of a good, independent audit program, the will to ensure proper upkeep and use may be lacking as well. Adequate training of inspectors, auditors and quality control staff is one of the main sources for a successful I/M performance in any country.

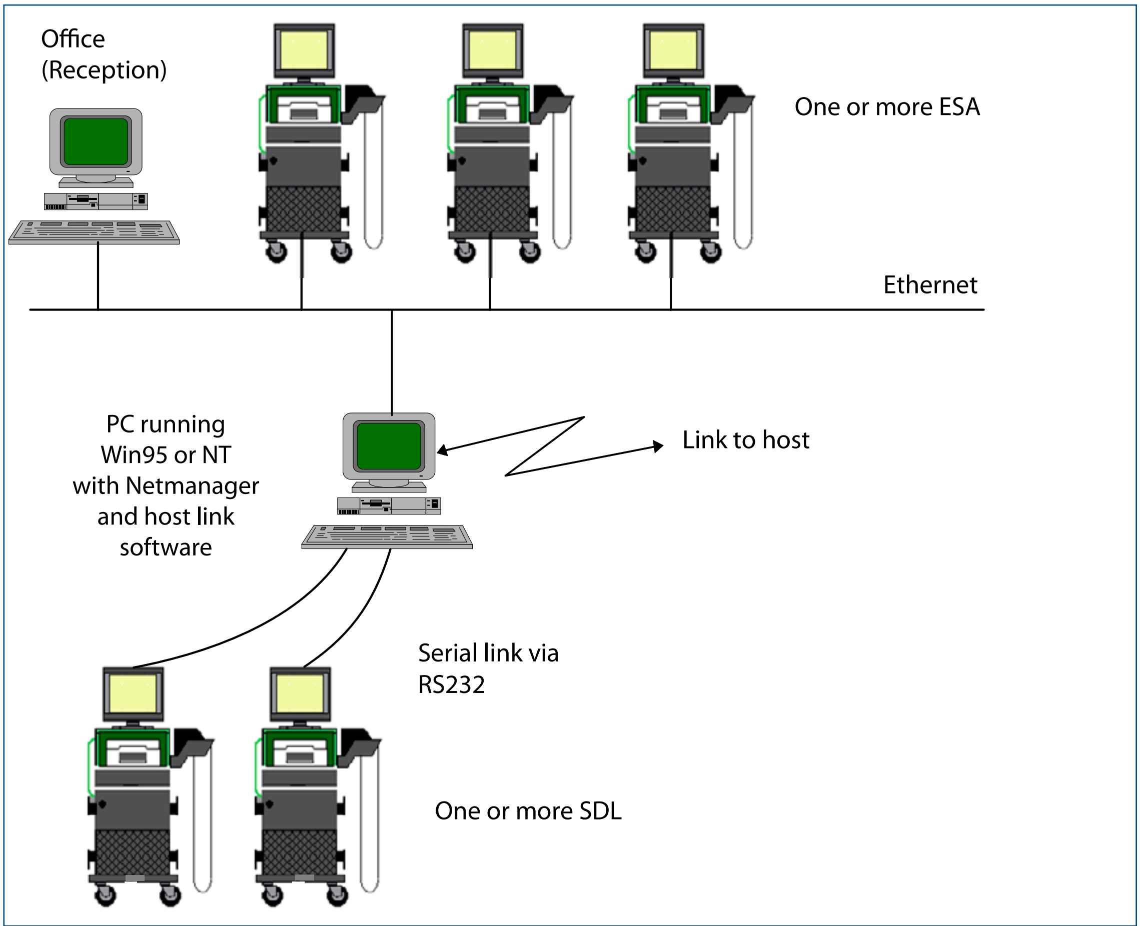


Fig. 38
Centralised survey system.

9. Conclusions

The only useful system of I/M emission procedures and additional safety checks (together summarised as roadworthiness testing) is a centralised system with the responsibility on the hand of the government and the contractor selected through an official tender process. Therefore, the introduction of a centralised system with a neutral organisation carrying out the tests on behalf of the government is a necessity. A decentralised system will fail to meet all of these requirements.

In addition, a regulation dealing with fines and other sanctions is urgently required to attract bidders (*e.g.* private contractor from overseas in a joint venture with a local contractor) to implement a useful roadworthiness and I/M system. If companies in advance of the official introduction make high investments, they must be able to rely on the fact that vehicles are tested in roadworthiness on a regular basis and that it is not more attractive to pay a fine or get a manipulated certificate through bribery.

There is a need to think about methods for getting better public cooperation and support for I/M programs. Suggestions include tax incentives or lower registration fees for cleaner vehicles. Strong but fair penalties for non-compliance can also play an important role.

National or regional governments do not have to offer any financial grants to the contractor, but have to offer the introduction of legal and binding requirements for mandatory roadworthiness tests, combined with fines, including legal requirements for all stakeholders. An international contractor together with a local company have the chance to implement simple but effective test devices, which require initial investments on the one hand, but the opportunity to start up new businesses in the country (see Figure 39). A guarantee of specific test fees, as well as fines and other consequences for vehicle users guaranteed by legal enforcement, is the incentive for the contractor, who has to supply the devices, train the staff and guarantee consistent test standards.

The local contractor also benefits. He creates job opportunities in a start-up business that is responsible on the local level for the efficient performance of the roadworthiness tests. Local repair shops and workshops have the opportunity to increase their business for maintenance works (the "M" in I/M) and other simple repair works which have to be done for failed cars or in advance to ensure that vehicles do not fail the tests. This creates job opportunities as well. The service industry must have sufficient equipment to properly repair vehicles. In addition, adequate training must be made available so that the mechanics and technicians are sufficiently skilled to repair the failed vehicles that come to their shops.

The main benefits are for the public; a message which should be conveyed by the government. Safer and cleaner traffic and a lower number of accidents caused by technical defects, combined with a system creating additional job opportunities as well, form a positive vision to work towards.

The shift towards more stringent emission standards for new vehicles should be followed by tighter in-use standards for the newer models as well. The test procedure should be shifted to a "loaded test" rather than an "idle test" for new vehicles.

Further air pollution abatement strategies

- Emission control system retrofit program for in-use vehicles (heavy duty vehicles, passenger cars, motorcycles) Module 4c: *Two- and Three-Wheelers*;
- Vehicle ban for entry of polluting vehicles in certain parts of the city Module 2b: *Mobility Management*;
- Age limits on public transport vehicles, commercial vehicles and motorcycles, Module 3c: *Bus Regulation and Planning*; and Module 4c: *Two- and Three-Wheelers*;
- Mandatory use of pre-mixed 2T lube oil for 2-stroke engines for motorbikes and motorcycles, Module 4c: *Two- and Three-Wheelers*;
- Use of compressed natural gas (CNG) and liquefied petroleum gas (LPG) as alternative fuel in urban areas, Module 4d: *Natural Gas Vehicles* and Module 4a: *Cleaner Fuels and Vehicle Technologies*.

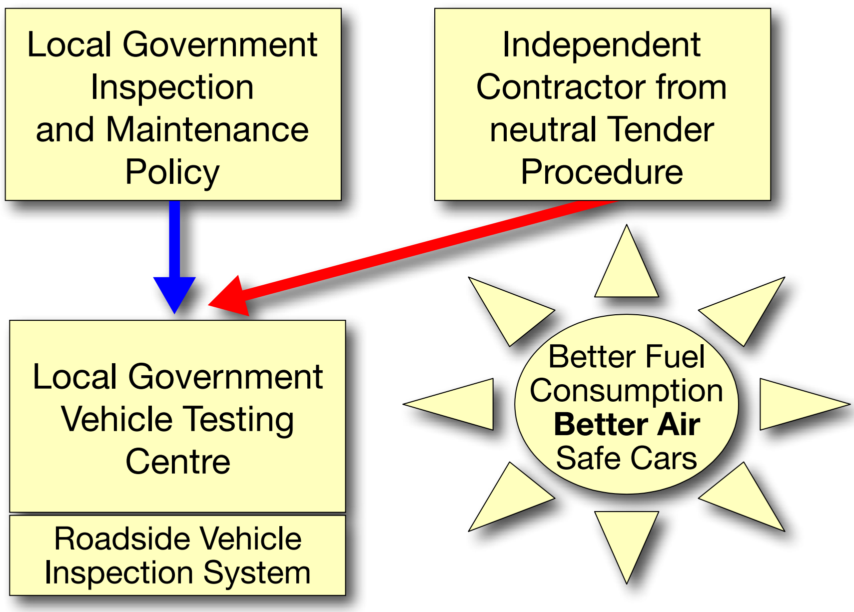


Fig. 39
Centralised survey system.

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