A Review of the Hong Kong Inspection and Maintenance Programme for On-road Vehicles

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Civic Exchange is a Hong Kong-based non-profit public policy think tank that was established in September 2000. It is an independent organisation that has access to policy-makers, officials, businesses, media and NGOs reaching across sectors and borders. Civic Exchange has solid research experience in areas such as air quality, energy, urban planning, climate change, conservation, water, governance, political development, equal opportunities, poverty and gender. For more information about Civic Exchange, visit http://www.civic-exchange.org.

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Preface & acknowledgements

In order to improve Hong Kong's roadside air quality, the HKSAR Government has taken several measures to control vehicle emissions, including imposing stricter new vehicle emission standards and mandating the use of ultra-low-sulphur fuel. The Clean Air Plan, jointly released in March 2013 by the Environment Bureau, Transport and Housing Bureau, Food and Health Bureau, and Development Bureau, highlighted the need for upgrading the inspection and maintenance programme to improve roadside air quality. The Environmental Protection Department of the HKSAR Government has just announced its subsidy programme for the replacement of catalytic converters and oxygen sensors on gasoline and liquefied petroleum gas (LPG) taxis and minibuses. It will also be launching a roadside tailpipe test on dynamometre and remote sensing programme for gasoline and LPG vehicles. All these are positive and major steps, and are encouraging to see.

However, a comprehensive vehicular pollution control strategy should also include a well-designed inspection and maintenance programme, as an effective inspection and maintenance programme ensures that the strategy's emission reduction targets can actually be realised.

This report looks at the role of inspection and maintenance in a comprehensive vehicular pollution control strategy, compares Hong Kong's current inspection and maintenance programme with international best practices, and suggests ways to improve the current programme.

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Yan-yan Yip
Chief Executive Officer

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Glossary of acronyms

ABS	Anti-lock brake system
CO	Carbon monoxide
CO_2	Carbon dioxide
CV	Constant volume sampler
DCTC	Designated Car Testing Centres
DCV	Diesel commercial vehicle
DPF	Diesel particulate filter
DOC	Diesel oxidation catalyst
EEV	Enhanced environmentally friendly vehicle
EMSD	HKSAR Electrical and Mechanical Services Department
EPD	HKSAR Environmental Protection Department
GVW	Gross vehicle weight
HC	Hydrocarbon
HKTET	Hong Kong Transient Emission Test
HSU	Hartridge Smoke Units
I/M	Inspection and maintenance
LPG	Liquefied petroleum gas
MEP	Ministry of Environmental Protection, People's Republic of China
N_2	Nitrogen
NO	Nitrogen monoxide
NO_2	Nitrous oxide
NO_x	Nitrogen oxides
O_2	Oxygen
O_3	Ozone
OBD	Onboard diagnostic system
PM	Particulate matter
PM_{10}	Particulate matter less than 10 micrometres in diameter
RSD	Remote sensing device
RSP	Respirable suspended particulates
SCR	Selective catalytic reduction
SHED	Streamlined, Heavy-duty Emission Test
SO_2	Sulphur dioxide
TA	Type approval
TD	HKSAR Transport Department
ULSD	Ultra-low-sulphur diesel
VOC	Volatile Organic Compounds

Executive summary

Hong Kong's air quality has been deteriorating in the past decade despite the government's efforts in enforcing increasingly stricter new vehicle emission standards and mandating the use of ultra-low-sulphur motor fuel. The Clean Air Plan for Hong Kong, which proposed various measures to clean up the air, highlights the need for upgrading the inspection and maintenance (I/M) programme to improve roadside air quality. An effective I/M programme is a core part of a comprehensive vehicle emission control strategy, as it ensures that the expected emissions reduction of any programme implemented is actually realised, whether it is replacing old and dirty vehicles with newer ones, or retrofitting high-emission vehicles with after-treatment devices.

In-use vehicles in Hong Kong, except for private cars below the age of seven years, are required to have emissions checked every year, but most vehicles are tested at idle (so-called unloaded tests); only ten per cent of diesel vehicles that undergo annual vehicle examination, and smoky vehicles identified by the Environmental Protection Department (EPD), police or voluntary spotters, are inspected using a loaded Lug-down test. Unloaded tests are commonly adopted by many countries/regions, especially for diesel vehicles, because they are quick, easy and cheap to conduct. But for Hong Kong, with almost all of its gasoline and liquefied petroleum gas (LPG) vehicles and over half of its diesel-fuelled fleet equipped with electronically controlled engines, the unloaded tests are no longer effective for identifying vehicle defects that may cause high emissions. In addition, unloaded tests are incapable of measuring emissions of nitrogen oxides (NOx). The Lug-down test, though better than unloaded tests, is not designed for measuring diesel vehicle particulate matter (PM) and NOx emissions.

The Environmental Protection Department (EPD) is going to launch a new tailpipe test and remote sensing programme for gasoline and LPG vehicles. This represents a major step in improving the government's capability to identify and force proper repair of high emission vehicles. Nonetheless, there are still some areas in which the current I/M programme could be improved, based on international best practices:

- **New I/M tests for diesel vehicles that measure PM, NOx and other important diesel emissions should be developed and adopted.** About a fifth of Hong Kong's NOx and PM emissions come from diesel commercial vehicles, but the current emission tests are not able to effectively detect high PM and NOx emission from these vehicles. A new tailpipe test programme, coupled with a roadside test/remote sensing programme, for measuring diesel vehicle PM and NOx emissions should be developed to effectively ensure that high-emission diesel vehicles are properly repaired or scrapped.

- **Quality control and audit of the vehicle test centres should be strengthened.** Currently, emission test results are mainly recorded manually, and most of the diesel vehicle testing records are only kept on paper. The government should consider establishing a fully automated test and quality control system, which can greatly improve reliability of the test results, deter fraud and enable easier and more effective audits of performance of test centres and individual testers.

- **Phase in the switch to gasoline/LPG vehicle dynamometre testing, and evaluate the cost-effectiveness of exempting clean private cars.** The new tailpipe test for gasoline and LPG vehicles requires significant capital investment. It is advisable that the government first mandates the test for commercial light vehicles like taxis and minibuses and assess the cost and benefit and feasibility of exempting the fraction of private cars that are identified 'clean' based on the remote sensing data. By doing so, the government can target use of I/M resources on the most polluting fraction of vehicles.

- **Strengthen collaboration between government agencies, including the EPD, Transport Department (TD), Electrical and Mechanical Services Department (EMSD) and other government agencies, and clearly define the role and responsibilities of each agency.** Various government agencies play different roles in the operation of Hong Kong's I/M programme. Closer collaborations among the agencies and a clear definition of the roles of each agency could ensure that as the I/M programme is upgraded, multiple agencies can coordinate their work effectively and implement any necessary changes smoothly.

- **Build public and political support through educating the public and elected officials on the health benefits of an upgraded I/M programme.** Public perceptions of the effectiveness, transparency and fairness of the I/M programme will affect the public's confidence and willingness to support additional funding for upgrading the programme. An ongoing education programme should be launched to keep the public informed of the benefits of the upgraded I/M programme and to demonstrate that the programme is fair and effective.

1 Introduction: The Role of Inspection and Maintenance in a Comprehensive Vehiclar Pollution Control Strategy

A Clean Air Plan for Hong Kong released by the Environment Bureau in March 2013 charts a roadmap for pursuing better air quality and reducing public health risks caused by outdoor air pollution. The plan highlights the importance of reducing vehicular emissions for improving roadside air quality, and identifies I/M as one of the areas that needs to be improved in order to reach that goal. To inform the plan for upgrading Hong Kong's I/M programme, this paper compares the current programme with international best practices and offers recommendations for improvements.

A comprehensive vehicle pollution strategy consists of four components: increasingly stringent new vehicle standards; specifications for clean fuels; programmes to assure proper maintenance of in-use vehicles; and transportation planning and travel demand management (see Box 1). In the past two decades, Hong Kong has made significant progress with reference to the first two components, and is a leader in Asia in mandating the use of clean fuel and vehicles:

Vehicle and fuel standards adopted in Hong Kong has been tightened since 2000

- Hong Kong has steadily improved its motor fuel quality since 2000. The strictest diesel and gasoline fuel standards (Euro 5 standards) were enforced in July 2010, though Euro 5 diesel fuel has been widely available in Hong Kong since late 2007 after the government reduced and later waived the tax on Euro 5 diesel fuel.[1]

- With respect to vehicle emission standards, Hong Kong has ratcheted down limits on new vehicle emissions since 1995. As of 1 June 2012, all new vehicles sold in Hong Kong must comply with Euro 5/V emission standards, placing the city among the most progressive countries and regions in Asia.[2]

- In addition to tightening standards for new vehicles and motor fuel, the government has also launched a series of programmes to promote the use of liquefied petroleum gas (LPG) for taxis and light buses, and to encourage the retrofit of in-use vehicles with after-treatment technologies, including diesel particulate filters (DPF) and diesel oxidation catalysts (DOC) (see Figures 1A and 1B) with the goal of reducing the rate of emissions from each vehicle.

A well-designed I/M programme is a critical part of a comprehensive emission control programme to identify on-road high emitters

Despite all these measures, ambient air pollution, especially roadside NO_2 and CO concentration, has not shown any clear declining trends (see Figure 1A and 1B respectively). This suggests the need for better controlling emissions from vehicles, not only when they are new, but after they have been in service for years. An I/M programme, if designed well and enforced effectively, could serve that goal by identifying vehicles with uncontrolled or exceedingly high emissions and ensuring that appropriate maintenance actions are performed. By regularly monitoring emission control performance of vehicles in operation, an effective I/M programme could help assure that vehicle control measures put in place, such as accelerating replacement of old dirty trucks or retrofitting vehicles with after-treatment devices, can actually realise the expected emission reduction benefits. Transportation planning and demand management, although a critical element of a comprehensive strategy, is outside the scope of this study, and should be examined in future research.

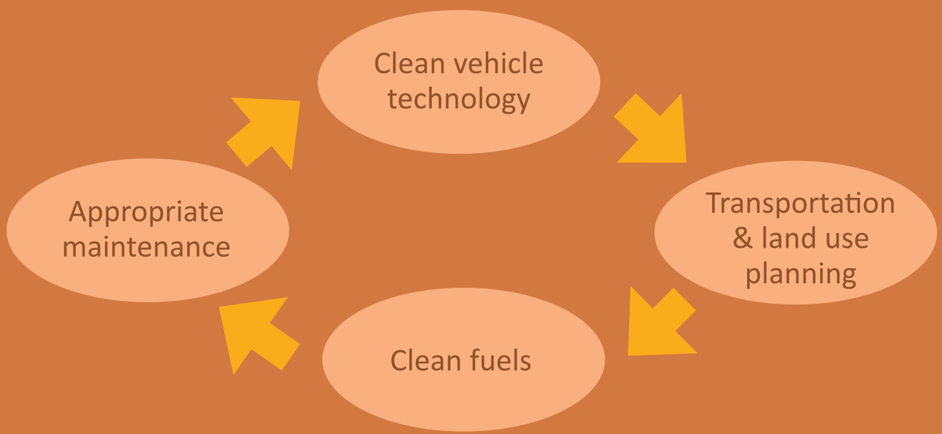
The remaining part of this paper is structured as follows: Section 2 summarises essential elements of a good I/M programme based on a review of literature and interviews with international experts; Section 3 provides an overview of Hong Kong's I/M programme; Section 4 gives recommendations for improving the current I/M programme; and Section 5 offers some concluding remarks.

Box 1: Effective strategy for controlling vehicle emissions

An effective vehicle emissions control strategy should cover the following four elements:

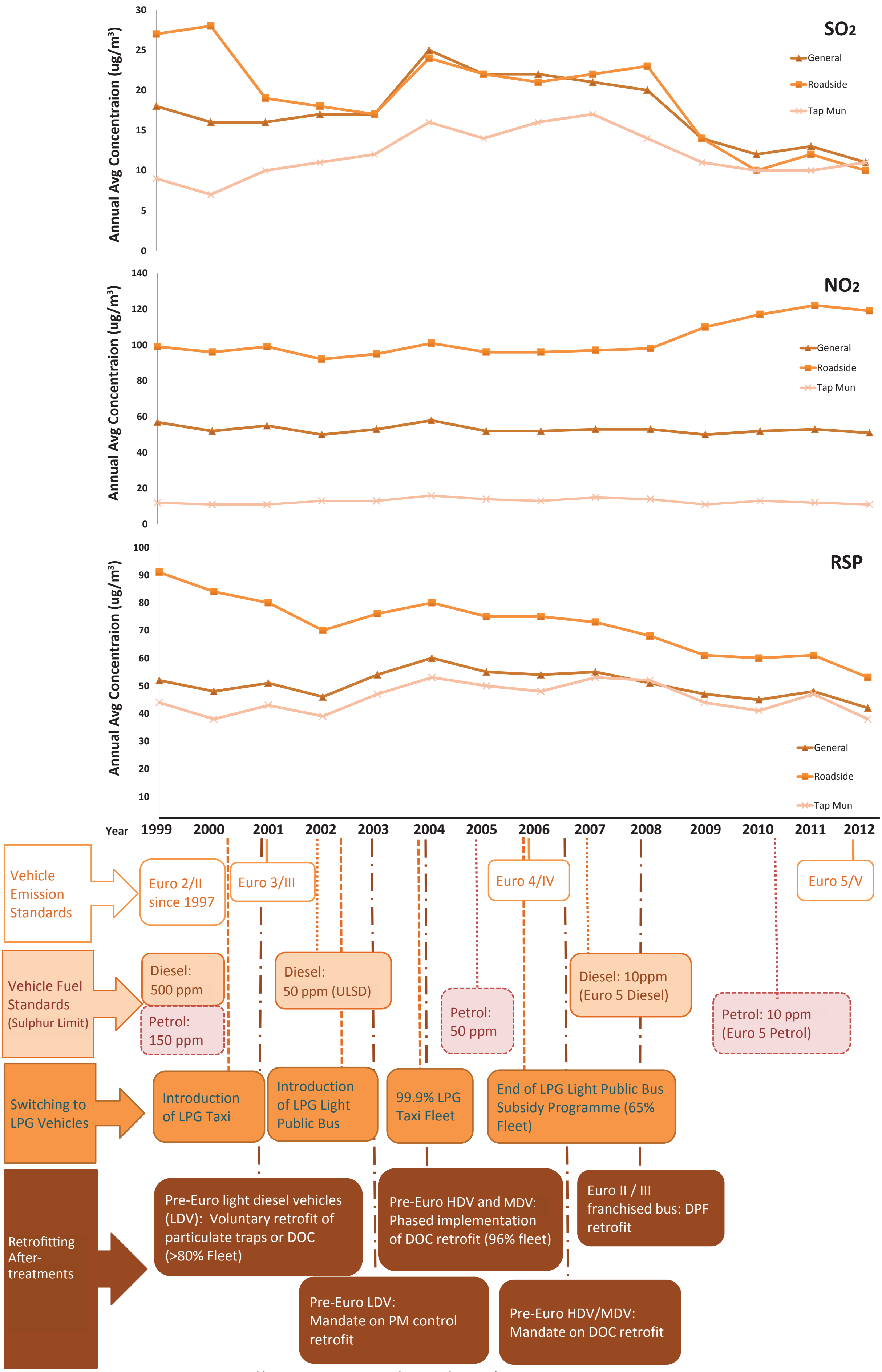
- **Reduce vehicle emissions per vehicle:** Promote the use of clean vehicle technologies by continuously tightening new vehicle emissions standards.
- **Reduce the total amount of driving:** Adopt effective land use and transportation planning policies to control the amount of driving while satisfying current and future mobility needs.
- **Use clean fuel that reduces vehicle emissions and enables the use of advanced emission control technology:** Promote the use of clean fuels by adopting and enforcing stringent fuel quality standards.
- **Keep real-world vehicle emissions low:** Encourage the appropriate maintenance of vehicles by implementing an effective vehicle inspection and maintenance programme.

Elements of a comprehensive vehicle pollution control strategy



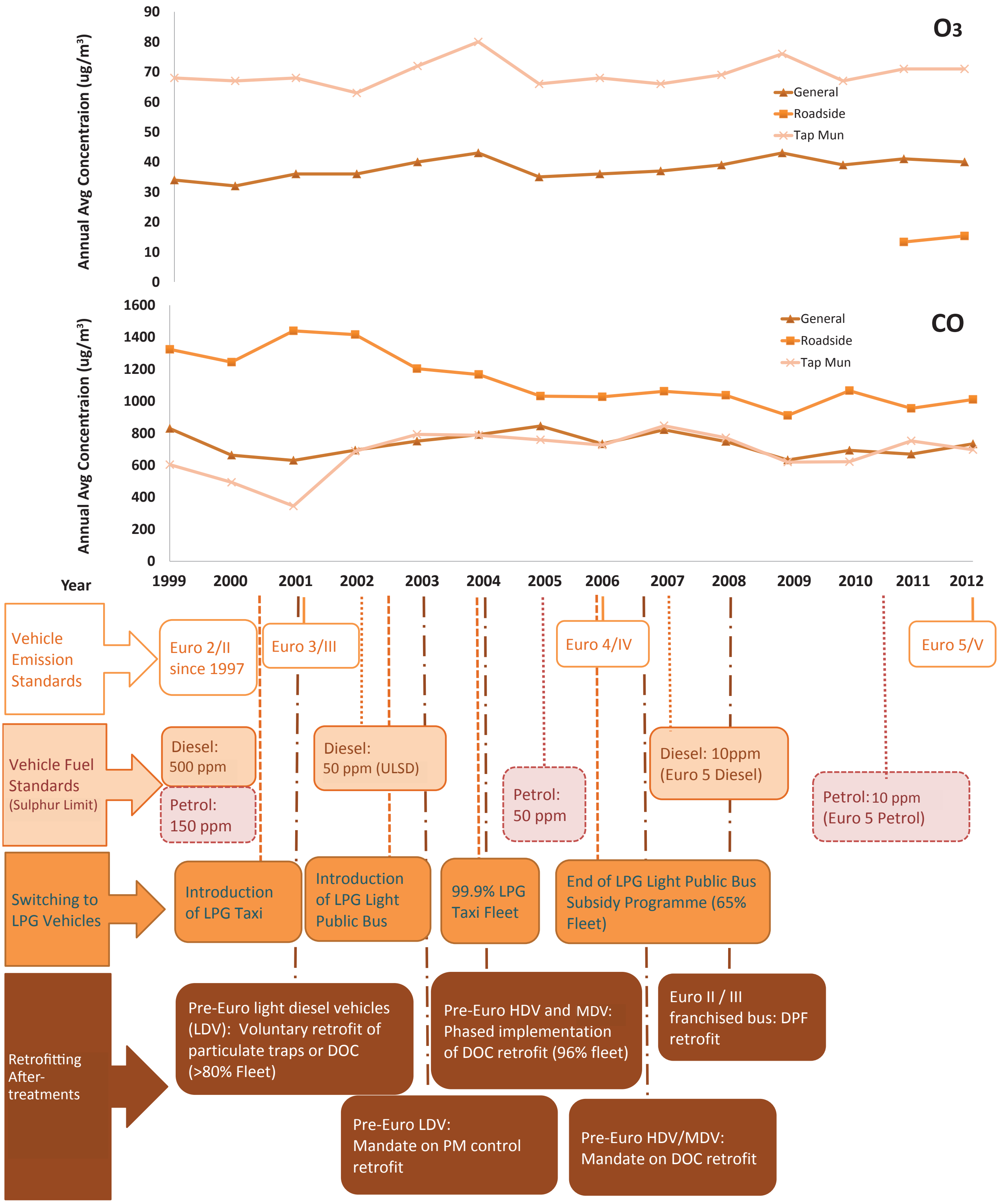
Source: Walsh, M P (2005), *Motor Vehicle Inspection and Maintenance: The World Experience*, http://www.walshcarlines.com/pdf/SIAT2005%20IM.pdf, accessed 15 April 2013.

Figure 1A: Air pollutant concentration and vehicle emission control measures implemented to date (SO_2, NO_2 and RSP)



EPD, *Air Quality Reports*, Table C3, http://www.epd-asg.gov.hk/english/report/aqr.html, accessed 14 May 2013. The annual average values for each pollutants of general stations and road side station were the arithmetic means from the Annual Average of Air Pollutants of the 11 general stations except Tap Mum, and the 3 roadside stations (Causeway Bay, Central and Mong Kok), respectively.

Figure 1B: Air pollutant concentration and vehicle emission control measures implemented to date (O_3 and CO)



EPD, *Air Quality Reports*, Table C3, http://www.epd-asg.gov.hk/english/report/aqr.html, accessed 14 May 2013. The annual average values for each pollutants of general stations and road side station were the arithmetic means from the Annual Average of Air Pollutants of the 11 general stations except Tap Mum, and the 3 roadside stations (Causeway Bay, Central and Mong Kok), respectively.

2 Inspection and Maintenance Programme International Best Practices

Taxis and LPG public light buses, which together account for only 4% of the fleet in Hong Kong, could contribute up to 40% of roadside NOx emissions

Vehicles rely on the proper functioning of components to keep emissions low. A malfunction of the air/fuel control or spark management system, or emissions control devices that have deteriorated or are destroyed or taken off, for instance, can increase emissions substantially. Therefore, a small fraction of vehicles (i.e. those that are high emitters), could contribute to a disproportionately large amount of emissions: a US study found that, typically, less than ten per cent of the fleet accounts for more than 50 per cent of emissions of any given pollutant;[3] In Hong Kong, tests conducted by the EPD found that taxis and LPG public light buses, which together account for only 4% of the fleet, could contribute up to 40% of roadside NOx emissions.[4]

Malfunctioning emission control components do not often affect vehicle drivability, and most harmful pollutants, such as CO, NOx and HC, are invisible; vehicle owners therefore have little incentive to perform maintenance to keep emissions low. For this reason, many jurisdictions have implemented I/M programmes with the goal of identifying high-emission vehicles that are in need of repairs and ensuring they are properly fixed.

Successful I/M programmes identify high emitters and ensure proper repairs

It is important to note that I/M programmes are intended to influence the behaviour response of the public, including vehicle owners, emission inspectors and service technicians. When designing or updating I/M programmes, careful consideration must be given not only to the technical aspects of the programme (test method and pass/fail criteria), but also to other elements that could enhance the quality of the emission tests and promote proper maintenance. In addition, policy makers must give careful consideration to the cost-effectiveness of the programme because high inspection costs can often weaken the support from the public and politicians that is critical to the success of the programme. Therefore, the success of an I/M programme is determined by whether it can i) identify high-emission vehicles in a cost-effective manner by targeted enforcement, and ii) induce vehicle operators to properly maintain and repair their vehicles by establishing a fair and credible system, ensuring that service technicians are well-trained, and educating drivers so that they understand the health benefits of keeping vehicle emissions low.

Table 1 summarises key aspects of an I/M programme based on existing literature and expert opinions. Details of each of the aspects will be discussed below and followed by a discussion of the current I/M programme adopted in Hong Kong.

2.1 Institutional design

2.1.1 'Test-only' vs 'Test-and-repair'

I/M programmes can be broadly grouped into two categories: A centralised 'test-only' system, where test and repair services are separated, or a decentralised 'test-and-repair' system, where the testing facilities perform both emission testing and vehicle repair services.

A centralised 'test-only' system is easier to manage

A test-only system can be run by the government or by contractors, and typically offers a limited number of test centres. A test-only system is considered superior to a test-and-repair system because:

- the smaller number of test centres signifies relatively easier government oversight;
- costs per inspection are lower, as facility and equipment costs can be spread over a higher number of inspections;
- a higher utilisation rate means lower overall investment costs on more sophisticated testing equipment if stricter test limits are to be enforced (see the section below on test procedure and test limits); and
- typically, labour costs are lower as the skills required for testing vehicles are less demanding than the skills for testing and repairing vehicles.

Some said that a 'test-only' system may be inconvenient to vehicle owners

Some experts argue that a centralised 'test-only' system may be of greater inconvenience to vehicle owners because of the smaller number of test stations, and that separating test and repair may also result in the 'ping pong' effect, which refers to the phenomenon whereby a vehicle owner needs to send the vehicle back for testing multiple times after the vehicle repeatedly fails the emission test, even after being repaired.[5]

Table 1: Essential elements of a good I/M programme

Element	Best practice	Advantages
I/M institutional design	Centralised I/M system where inspections are separated from maintenance function	Easier facility oversight by the government Potentially lower cost per test if a large number of vehicles are tested in each facility
Oversight and quality assurance	Ensure audits are fully built into the overall programme design and accounted for in the fee structure	Deter frauds, establish credibility and effectiveness of the I/M systems
	Set test fees at a reasonable level that will allow private operators to make a sufficient profit to maintain, replace and upgrade equipment as required	Assure good quality testing is performed
Technical issues	Use loaded testing for electronically controlled vehicles	Enable more effective identification of high emitting vehicles, and lower chance of false pass and false failure
	Tighten in-use emission standards for new vehicles in tandem with adoption of more stringent new vehicle standards	Continuous improvement of I/M programme effectiveness
	Assure frequency of inspections varies for vehicles with differing mileage accumulation rates and with more or less durable emission control systems	Ensure that high mileage/usage commercial vehicles, like taxis, are adequately inspected and properly maintained
Compliance promotion and enforcement	Link I/M with registration data so that failure to present proof of inspection leads to denial of registration	Strong inducement to encourage vehicle owners to send vehicles for inspection
	Include a detailed data management system to enable transmission of all real-time test data as generated	Allow oversight agencies to collect data for enhancing the enforcement programme, and minimise chances of falsifying data if testing device automatically inputs and transmits testing data to the database
	Complement I/M with roadside testing or remote sensing	Catch gross emitters that use temporary fixes to pass I/M requirements
	Raise public awareness of health benefits that can result from a successful I/M programme	Ensure public acceptance and encourage participation in I/M inspection
	Develop performance standards for I/M and penalise poorly performing stations	Guarantee quality of the I/M programme as key to assuring public support
Obtaining management/ inter-agency support and managing resources	Solicit support by senior decision makers and gain institutional capacity to manage and regulate the system	Adequate funding and resources allocated to ensure the programme is not plagued by corruption and poor quality control
	Develop an adequate fee structure in which affected vehicle owners pay the full costs of the I/M programmes (including costs for auditing and overseeing the programme, road-side testing, etc.)	Ensure sufficient funding is set aside
	Initiate full dialogue with all appropriate government agencies at the early stage of design	Assurance that all key stakeholders agree with their respective roles and have ownership of the programme
Paying attention to maintenance	Ensure service industry has sufficient equipment and knowhow to properly repair vehicles	Realise the emission reductions promise of the I/M programme
	Give sufficient lead time to allow the service industry to equip itself to repair failing vehicles when tightening I/M requirements	Ensure that failed vehicles are properly repaired and emissions are reduced

Source: Modified from Fung, F et al. (2010), *Overview of China's Vehicle Emission Control Program: Past Successes and Future Prospects*, Table 5.1, March, the International Council on Clean Transport, http://theicct.org/sites/default/files/publications/Retrosp_final_bilingual.pdf, accessed 30 June 2013.

But 'test-only' system can minimise fraudulent

Despite these drawbacks, international experts predominantly favour test-only facilities over test-and-repair facilities.[6] While adopting a test-only system does not guarantee the elimination of fraudulent inspections, it can contain the task of government oversight within a more manageable scale (because of the smaller number of test centres). The ability to avoid fraudulent inspections under a test-only system far out-weighs the inconveniences to vehicle owners.

Different countries/ regions also choose 'test-only' system

In the US, where different states are free to choose the types of I/M programmes they use, auditors have found improper inspections as high as 50% in test-and-repair I/M programmes.[7] Mexico, which now operates one of the world's best I/M programmes, has overhauled the initial hybrid programme (which saw both test-only facilities and test-and-repair facilities operating in parallel) with no effective surveillance system, to a centralised test-only programme. The change to a centralised programme has allowed the government to institute a strong system of oversight and quality assurance (see Box 2).[8]

Another advantage of a centralised programme is that it allows the costs of equipment and labour to be shared by a larger number of inspections. As emissions control systems on modern vehicles become more sophisticated in order to meet increasingly stringent standards, a change of test method and upgrade of testing equipment will become inevitable. The ability of a centralised programme to spread the costs of equipment investment and training for labour over a larger number of inspections certainly makes it the preferred choice over a decentralised programme.

2.1.2 Oversight and quality assurance — inspect the inspectors

An effective oversight and quality assurance programme is critical, as it guarantees that high-emission vehicles are indeed spotted so that necessary repairs can be made. A fair and effective programme also helps secure public and political support.

A good quality assurance programme should be incorporated with an audit and automated system

A good quality assurance programme should include the following elements:

- Audits: Calibration audits of test equipment, audits of test centres using the data reported, and covert audits of test centres in cooperation with law enforcement.

- Real-time I/M test results delivered to a centralised database as generated to minimise the chance of data manipulation. Careful analysis of collected data could help policy makers identify invalid data, compare performances of test centres and inspectors (e.g. check abnormal test results as signs of fraud), evaluate compliance with I/M requirements by linking with registration data, and evaluate if changes of the standard (pass/fail criteria or test procedures) are needed. Many of the successful I/M programmes, such as those instituted in Mexico and Greater Vancouver, have established centralised databases.[9] The Chinese Ministry of Environmental Protection (MEP) is also proceeding with the establishment of a centralised I/M database to provide better oversight.

As a rule of thumb, the less the test and audit systems need to rely on human judgment and manual actions, the more reliable the test and audit results. An automated test system that can automatically make pass/fail decisions and transmit data in real time to an oversight agency is therefore best.[10]

As an example, Box 2 summarises key elements of the oversight and quality assurance system instituted for the I/M programme in Mexico.

A reasonable fee structure should be setup to support long-term operation needs

Policy makers should ensure that the responsibility of the regulatory agency for quality assurance is clearly specified, and that sufficient resources (whether from inspection fees or from the general budget) are set aside to get the job done. Lastly, a fee structure should be set up such that the contractors are allowed to have adequate profits and can have funding set aside for maintaining, replacing and upgrading equipment, so that in turn the I/M system is less prone to fraud.

Box 2: The Mexico I/M programme's oversight and quality assurance system

The I/M programme in Mexico is seen as a role model for all developing countries. The following quality assurance and audit measures were instituted and have effectively deterred fraudulent inspections and corruption:

- Emission test results can only be seen in a central room, and staff on the test lanes conducting the test cannot see the test results; this discourages any tampering with the test equipment or vehicle and deters manipulation of the test.
- Tests are controlled by computers and all data are recorded automatically and electronically; this eliminates paper records that may invite fraud or inadvertent error.
- Test data, access data and calibration data are transmitted to a centralised authority in real time, as generated, and analysed thoroughly.
- The data are audited remotely at the centralised location as follows:
    1. Second-by-second emission test data pattern of tests of similar cars that have passed the test (e.g. Corolla/Civic of a given model and year) in different test centres are compared. If the vehicle's traces have a different shape, a 'flag' is raised for the test lane of that centre. If a test lane or centre gets an unusually high number of flags (beyond what could be due to statistical variance), the test lane or centre will be identified for further investigation.
    2. Test results calculated from the second-by-second emissions data are compared to the test results reported by the centre; different results suggest possible tampering.
    3. To ensure that one car is not being used to generate multiple certificates, the computer server compares the second-by-second emissions data pattern of one car with those of other cars being tested on the same test lane, and other test lanes in the same test centres.
    4. All access data and calibration data are also analysed for anomalies.
- Cameras are installed at all test centres and transmit live video feeds 24 hours every day to enable remote surveillance; live videos are broadcast online (http://www.sma.df.gob.mx/verificentros/verive/consulta.php); a hotline is set up for the public to report any suspicious acts; and the cameras can be controlled via the internet to zoom in and see the letters and numbers on the registration documents, etc., that are used for data entry.
- The test equipment is audited once a month by an independent ISO-certified materials standards laboratory to ensure that test equipment is properly maintained and that consistent test results are generated across all test lanes and centres. This helps to establish the credibility of the I/M test centres.
- A vehicle counting system is set up at each centre which is totally independent of the test equipment. The count checks the number of vehicles that enter and leave the test centre and each lane. The timing from the vehicle count is cross-checked against the verification process by the central server.
- All test personnel are required to be certified, and a system is in place so that a tester dismissed in one test centre due to fraudulent inspection cannot be hired by a different centre.

Sources:
Communications with John Rogers of the Sustainable and Emissions Services Company (18 May 2013);
PA Government Services (2004), *Vehicle Inspection and Maintenance Programmes: International Experience and Best Practices. A Report for the Office of Energy and Information Technology*, US Agency for International Development, http://pdf.usaid.gov/pdf_docs/PNADB317.pdf, accessed 15 April 2013.

2.2 Test procedures and emission standards

2.2.1 Test procedures — tailpipe emission testing

I/M programmes shoud be a time- and cost-effective indicator of high emitters

Countries around the world have adopted vehicle emission standards for new vehicles which all new models must demonstrate that they meet before they can be manufactured or imported. The procedure for establishing compliance with new vehicle standards (known as certification tests in the US, and type approval tests in Europe) is elaborate, and tests are run on a treadmill-like instrument called a dynamometre in order to mimic real-world driving conditions. Emission tests are conducted using expensive, laboratory-grade equipment to ensure that the estimated emission level attains the required precision.

For I/M programmes, shorter and simpler test procedures are used so as to be able to perform a large volume of inspections every day at reasonable costs. The goal of an I/M test is not to precisely determine if the emissions level of an in-use vehicle meets new vehicle standards; rather, it is designed to identify vehicles with high emissions, which is an indicator of failures of parts associated with emissions control. Various types of short test have been developed.[11] They can be put into three groups: unloaded tests, steady-state loaded tests and transient loaded tests.

a) Unloaded testing

Unloaded tests are cheap and easy to conduct...

Unloaded tests are conducted with the vehicle transmission in neutral position with no external load exerted. Because the tests are short, easy and cheap to conduct, they are the most commonly used I/M tests (see Table 2). An unloaded test requires simple garage-grade air analysers, with no need for dynamometres. The widely used test for gasoline vehicle I/M programmes, idle/fast idle test, can effectively identify malfunctioning air/fuel mixture preparation systems in carbureted cars (pre-Euro vehicles).

but they are unable to check NOx and ineffective for evaluating modern vehicle emissions

While unloaded tests are used in many countries, it is well known that they cannot be used to measure NOx — a precursor for ground-level ozone — because NOx emissions at idle are negligible. In addition, for vehicles that are electronically controlled (Euro 1 and newer light-duty vehicles, and Euro III or newer heavy-duty diesel vehicles), idle tests may not be able to detect defects that cause high emissions (e.g. malfunctioning sensors, degraded three-way catalysts, etc.).[12]

Table 2: I/M testing procedures adopted by selected countries

a) Light-duty gasoline vehicles

Country/ Region	Vehicle Type	Sub-type/ manufacture date	Test Method	CO	HC	NO	NO_x	OBD (if available)	λ	λ test condition	Remarks
China National	Light-duty gasoline vehicle (LDGV)		Idle/ Fast Idle	√	√						
			ECE 15 Cycle (transient)	√	√		√		√	Electronically controlled vehicles	Required for all perfectural level or higher level cities by 2015[1]
Beijing, China	LDGV		BASM5024 (steady-state)	√	√	√		√	√	Vehicles with electronic fuel injection system	
			BASM2540 (steady-state)	√	√	√		√	√		Performed only if failed BASM5024
			Idle	√	√						Performed on carbureted cars only
Hong Kong, China	LDGV	In or before 1974	Exempt								
		Between 1975 and 1991	Idle	√							
		In or after 1992	Idle/Fast Idle	√					√		
Japan	LDGV		Idle	√	√						
Singapore	LDGV		Idle	√							
California, US	LDGV		Idle/Fast Idle	√	√						Conducted in areas with Basic I/M programs, or on vehicles upon change of ownership
			ASM Test	√	√		√	√ (1996 or newer models)			Conducted in areas with the most serious air quality problems, and which are required to implement enhanced I/M programs
Colorado, US	LDGV	In or before 1981	Idle/Fast Idle	√	√						Test performed in the enhanced I/M program
		In or before 1982	IM240 (transient)	√	√		√	√ (1996 or newer models)			
Vancouver, Canada	LDGV	In or before 1991	ASM (steady-state) and Idle	√	√		√				
		In or after 1992	IM240 (transient)	√	√		√	√			
			Idle	√	√		√	√			Performed only if the vehicle cannot be placed on dynamometre
European Union	LDGV	Not controlled by three-way catalytic converters	Idle	√							
		Controlled by three-way catalytic converters	Idle/ Fast Idle	√				√	√		

b) Heavy-duty diesel vehicles

Country/ Region	Vehicle Type	Test Method	Smoke/ Opacity	Other pollutants	OBD
Australia	All diesel vehicles (not mandatory)	DT80, DT60 on chassis dynamometre	√	NOx, PM	
China National	All diesel vehicles	Free Acceleration	√		
Beijing, China	All diesel vehicles	Lug-down	√		
		Remote sensing	√		
Hong Kong, China	All diesel vehicles	Free Acceleration	√		
	Suspected smoky vehicles and 10% random sample	Lug-down	√		
Japan	All diesel vehicles	Free Acceleration	√		
Singapore	Vehicles undergoing I/M inspection	Lug-down	√		
	Road-side cross-border truck inspection	Free Acceleration	√		
California, US	Vehicles with GVW between 6,000 lbs and 14,000 lbs	Free Acceleration	√		√ (manufactued since 1998 and if OBD II is installed)
	Vehicles with GVW over 14,000 lbs (no regular inspection, only conducted at roadside inspection)	Free Acceleration	√		
Colorado, US	Large fleets that take part in Diesel Opacity inspection Program	Free Acceleration	√		
	Small fleets and individual that take part in Diesel Opacity Inspection Program	Lug-down	√		
Vancouver, Canada	All diesel vehicles	Free Acceleration	√		
European Union	All diesel vehicles	Free Acceleration	√		

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Loaded tests are more effective but cost more to perform. It can simulate real-life operation of on-road vehicles

b) Loaded testing

Loaded tests involve engine loading, so can be used to check vehicle NOx emissions. To perform a loaded test, a vehicle is put on a dynamometre and is either driven at constant speed and load (steady-state loaded tests) or operated following a test sequence of acceleration, deceleration, cruise and idle modes, which simulates real world driving (transient loaded tests). Running transient tests is usually more costly: while the results of steady-state tests tend to be presented in concentration (per cent or parts per million), transient tests require the conversion of emissions concentration into mass per mile or tonnes per year. Thus, in addition to a gas analyser, a Constant Volume Sampler (a flow measurement device) is needed, which increases the cost of the test. Also, running a transient test requires the use of a more expensive transient-type dynamometre and more highly skilled (hence better-paid) inspectors, and the test can take longer to complete.[13]

Idle test is commonly used for testing gasoline vehicles

c) Tailpipe testing for gasoline vehicles

The idle test and idle/fast idle test (also known as the two-speed idle test) are tests which are commonly used to measure in-use emissions from gasoline vehicles. Some regions in the US, Mexico and the Greater Vancouver region have adopted loaded tests for their light-duty vehicle I/M programmes. The US, in particular, provides some useful insights regarding the effectiveness of different types of testing, as the types and stringency of I/M programmes which are adopted in different states vary widely.[14]

Pilot tests conducted by the US Environmental Protection Agency (US EPA) in the early 1990s suggested that the IM240 test — a transient loaded test — in conjunction with evaporative system purge and pressure testing, was the most cost-effective way to test in-use light-duty vehicle emissions at that time. It was considered to be superior to steady-state loaded tests, such as the Accelerated Simulation Mode test (ASM), in terms of the excess emissions identified, as well as the number of vehicles falsely failed. Later, it was determined that the ASM could produce emission reductions comparable to IM240, depending on where the failure cut-points were set, even though setting tighter cut-points comes with the trade-off of increasing the number of false failures.[15]

Regulators should choose tests which are suitable for their countries/region

In summary, loaded tests are more effective than unloaded tests in terms of detecting high emissions vehicles in need of repairs.[16] With loaded tests, transient tests are more stringent than steady-state tests (hence can deliver a higher level of emission reduction) but cost more to perform; the cost/benefit balance is not absolute and the needs may vary from place to place. It is the regulators' choice as to whether the additional emissions benefits and accuracy is worth the extra investment in equipment for transient loaded testing. The choice of the test procedure ultimately needs to be balanced alongside considerations of accuracy, manipulability and costs.

It should be noted that the US has gradually shifted towards relying solely on the onboard diagnostic system (OBD) test for all OBD-equipped vehicles (1996 or newer vehicles) in the past decade. See Section 2.2.2 for more discussions on the OBD test.

d) Tailpipe testing for diesel vehicles

Free Acceleration Smoke test and Lug-down test are commonly used for diesel vehicles

For diesel vehicles, there is a lack of robust and commercially available testing equipment to quickly and accurately measure diesel particulate emissions. Smoky vehicles are seen as a nuisance, and the presence of smoke is associated with poor combustion and indication of possibly higher PM and NOx which could be caused by engine malfunction or maladjustment, or by use of improper fuel. Therefore, many regulators have been focusing I/M programmes for diesel vehicles on opacity/smoke.

The most commonly used opacity tests are the Free Acceleration Smoke test and the Lug-down test. The Free Acceleration Smoke test measures the maximum smoke when the vehicle is operated at full throttle while the transmission is in neutral. The loaded Lug-down test is performed by gradually increasing the load of the dynamometre (or the vehicle brake) to pull back engine speed until the engine is labouring or 'lugging'. Nearly all regions that implement diesel I/M programmes use the Free Acceleration opacity/smoke test. A few regions, like Colorado in the US, Hong Kong, Singapore and Beijing, use the Lug-down test (see Table 3).[17]

Free Acceleration Smoke test is not effective for monitoring NOx and PM

The Free Acceleration Smoke test is most useful as a screening tool, but is not an effective I/M test for vehicle PM and NOx emissions. Because smoke levels are influenced by the way in which the test is conducted, it is prone to manipulation. In addition, the test results have shown to be associated with high numbers of errors of commission (vehicles wrongly identified as faulty); hence, lenient standards are typically set to minimise false failures.[18]

Lug-down test is not designed for measuring NOx and PM

The Lug-down test is far less easy to manipulate and has shown to be more effective than the Free Acceleration Smoke test in forcing thorough repairs for reducing visual smoke.[19] However, the Lug-down is not designed for measuring PM and NOx emissions. Many studies have shown that the correlation between exhaust smoke and particle/NOx emissions from diesel vehicles is poor, even when measured under a controlled load on a dynamometre.[20] Therefore, even if the Lug-down test can force repairs that reduce smoke, particle or NOx emissions are not necessarily reduced. It was also found that diesel vehicles that are repaired to reduce visual smoke may have increased NOx emissions.[21]

A loaded test is needed for screening high PM or NOx emitting diesel vehicles, and has been adopted by some countries/regions

Recognising the limitations of opacity testing, some regions have shifted or are planning to use loaded testing to measure in-use diesel vehicle emissions. Australia has adopted a loaded transient test (DT80), which measures NOx, PM, CO and HC emissions from in-use diesel vehicles.[22] In 2011, the EU commissioned a study to explore cost-effective ways of measuring PM, NOx and NO_2 emissions from all on-road vehicles, including heavy-duty diesel vehicles. The study found that there is not yet a proven, commercially ready analyser for PM and NOx.[23] China has launched studies to look into the feasibility of using loaded tailpipe tests to measure NOx, NO_2 and PM emissions from heavy-duty diesel vehicles.[24] Rather than looking for alternative tailpipe tests for diesel vehicles, the US EPA started enforcing OBD requirements for heavy-duty vehicles from model year 2010,[25] with the plan to use OBD as the main I/M test for heavy-duty trucks.

2.2.2 Onboard Diagnostic System testing

OBD checks malfunction of vehicle components

Modern vehicles with electronically controlled engines are equipped with computer-controlled OBD systems, which monitor the performance of some of an engine's major components including those responsible for or related to controlling emissions. The OBD checks and signals various types of malfunction, and stores the error codes which can be used by repair technicians to quickly pinpoint problems and more effectively repair vehicles.

OBD tests gradually replaced tailpipe tests in the US

OBD testing has the potential to replace tailpipe emission I/M testing. All US states that administer I/M programmes were required to undertake OBD II testing for light-duty vehicles so equipped (1996 or newer vehicles) by no later than 2005. Since the share of non-OBD-equipped vehicles gradually decreases through normal attrition, it becomes harder to justify the costs of maintaining dynamometre tests for a shrinking non-OBD fleet, more states are expected to switch to OBD-only tests.[26] As of 2009, all states in the US except for Colorado and California rely on OBD to test nearly all their 1996 and newer vehicles. In the EU, OBD was introduced as a new vehicle emission requirement, starting with Euro 3 light-duty vehicles and Euro IV heavy-duty vehicles. Starting from 2009, OBD has been permitted as an alternative to I/M emission measurement for gasoline light-duty vehicles (Directive 2009/40/EC).

OBD tests are fast, effective and cheap to operate, but not universal

In the US, the EPA and state authorities have found that, in general, OBD tests can more effectively identify emission-related malfunction on in-use vehicles than tailpipe emission tests, as well as imposing stricter emissions requirements, and hence could achieve better emissions reduction.[27] In addition, the OBD test is faster to complete (five minutes to complete an OBD test versus 10-30 minutes for tailpipe tests, depending on the test cycle) and cheaper to operate (OBD inspection equipment can be as little as ten per cent of the cost of an analyser and a dynamometre), so inspection costs for vehicle owners are lower.[28] Based on analysis comparing OBD testing to traditional tailpipe testing, the EPA believes that OBD testing is the best way to test OBD-equipped vehicles in terms of emission reductions, pollution prevention, cost, convenience, accuracy, repeatability, test time, fraud detection, repair diagnosis and validation, and consumer protection.[29] In the EU, however, some studies have identified various issues with EOBD (the European OBD system) and consider it not yet suitable for replacing direct emission testing.[30]

Lack of standardisation and susceptibility to fraud may hinder the use of OBD tests outside the US

Outside the US and Canada, there is no standardised OBD data protocol, and this could present a major obstacle for other countries/regions seeking to incorporate the OBD test into an I/M programme. In addition, the integrity of an OBD-based inspection could be greatly compromised if inspection technicians obtain OBD data from a surrogate vehicle which has no malfunctions (so-called 'clean scanning'). Clean scanning is reportedly a serious issue for OBD-only programmes in the US,[31] but there are contractors with experience of designing computer programmes for the detection of clean screening and other types of cheating. There are also, reportedly, contractors with strong experience in developing a universal OBD scan tool and a data management system which can support regulators in successfully addressing the OBD standardisation problem.[32]

2.2.3 Emission testing pass/fail criteria and inspection frequency

Pass/fail point should be set to fail the most polluting vehicles

The overriding goal of an I/M programme is to identify the dirtiest fraction of in-use vehicles and make sure those vehicles are repaired so as to lower emissions. When deciding the pass/fail point, policy makers should evaluate the statistics of the distribution of emission levels and the repairs and costs needed for fixing the high emission vehicles. A good choice should balance the need for setting a set of strict enough criteria that fails the most polluted fraction of in-use vehicles, but not one that is so stringent that many vehicles are failed and public support is eroded.[33]

Cleaner vehicles could be subject to less frequent inspection

In addition, policy makers should make sure that the in-use emission standards for I/M programmes are tighter for newer/lower emission models, as new vehicles are subject to increasingly stringent emission standards. A common practice adopted by I/M programmes in the EU and other major auto markets is to vary the I/M test standards according to the year a vehicle is manufactured so that newer vehicles are subject to stricter standards.

With regard to the frequency of inspection, since the deterioration of emission-control-related components correlates more closely with the amount of driving, policy makers should ensure that the inspection frequency varies with differing mileage accumulation rates and the durability of emissions control devices. Commercial vehicles with high mileage such as taxis, public light buses and buses should be subject to more frequent inspection.[34]

2.3 Compliance promotion and enforcement

A few measures have been used by countries around the world to encourage vehicle owners to bring their vehicles in for I/M testing and to carry out the necessary maintenance and repairs to meet standards. These measures include:

- Linking I/M tests with registration and checking for valid I/M certificate;
- Conducting roadside emission inspections/remote sensing;
- Citizens reporting smoky vehicles; and
- Raising public awareness.

2.3.1 Linking I/M tests with registration and checking for valid I/M certification

Failing I/M test denies registration renewal of vehicle

Making compliance with I/M a requirement for being able to operate a vehicle is a very powerful tool for enforcing the in-use vehicle emissions requirement. Where I/M compliance is a prerequisite to vehicle registration, environmental agencies could leverage the police to help enforce I/M requirement and vehicle registration at the same time. These are common practices in many developed countries where regular registration is mandated. While linking I/M with registration requires the coordination of multiple agencies, it could be facilitated through establishing a computerised vehicle registration system, which automatically denies registration renewal if a vehicle fails the I/M test or if an I/M test has not been performed.

2.3.2 Roadside inspection and remote sensing

Roadside emission inspection can identify temporary fixed vehicles, but cannot replace tailpipe emission test

Roadside emission inspection is commonly used in many countries to identify vehicles with excessively high emissions. It deters vehicle owners from using temporary fixes to reduce emissions only on the day of inspection (the so-called 'clean for a day' fix), so serves well as a complement to I/M tailpipe tests. Roadside inspection, however, cannot replace tailpipe tests at a fixed station because, typically, only simple emission (free acceleration) tests can be undertaken at the roadside, and roadside inspectors can only screen a small fraction of vehicles. Some regions, such as Changzhou city in China, have enhanced the roadside test by using mobile dynamometres. In such case, enforcement officials can conduct roadside emission tests following the I/M test cycle, and the roadside test results can then be used for enforcement.

Remote sensing is an effective tool to identify dirty and clean in-use vehicles and characterise their fleet emissions

As technologies advance, remote sensing device (RSD) technology is becoming a more common approach to conducting roadside inspections because the technology can be used to collect emissions data from a large number of vehicles as they travel on the road without disrupting traffic. RSDs coupled with licence plate recognition devices are used effectively to identify light-duty vehicles with high in-use emissions (so-called 'dirty screening') for possible I/M re-inspection, identify low-emission vehicles ('clean screening') which can be exempted from regular I/M inspections, and characterise in-use fleet emissions in order to evaluate vehicle inspection programmes. After commercial RSDs first emerged in the early 1990s, these three general applications were extensively studied and demonstrated in the United States between the mid-1990s and early 2000s, during which time the US EPA issued guidance documents recognising each.[35]

Remote sensing has been used in some countries/ regions, ...

As on-road RSD technology and methodology matured, remote sensing was demonstrated to be an effective complement to regular vehicle inspection. Remote sensing is now used in Hong Kong, a few Chinese cities and several US locations (including Colorado, Virginia, Texas and Ohio) to screen vehicle emissions on-road and is being considered for such application elsewhere in North America (including Mexico City DF and the Canadian province of British Columbia). Remote sensing is used in Europe (Spain, Switzerland and the UK), Latin America (Brazil and Chile) and Asia (South Korea) to characterise in-use emissions of vehicles for trends analysis, and to validate and improve motor vehicle emission inventories and models.[36]

however, it is not effective on emissions from heavy duty diesel vehicles

To date, nearly all the current ongoing remote sensing programmes target light-duty vehicles, with the exception of Boston's and Beijing's programmes, which also measure smoke emissions from municipal buses and heavy-duty vehicles, respectively.[37] Measuring emissions from heavy-duty diesel trucks using remote sensing is more challenging, because the height and location of tailpipes on heavy-duty trucks are not as uniform as those on passenger cars. Another reason is that diesel and gasoline/LPG engines operate on different combustion chemistry. Diesel engines do not emit an approximately constant carbon dioxide concentration, while gasoline engines and LPG engines that run on stoichiometric burn conditions do. The absence of a constant carbon dioxide concentration from diesel engines makes it difficult to reliably determine diesel emission concentration by current remote sensing methods.

Remote sensing on heavy duty diesel vehicles is now the study focus

The Greater Vancouver region and Los Angeles conducted pilot studies recently using RSDs to measure diesel truck emissions (NO, NO_2, PM, etc.). While the Los Angeles study at the port continues, the Vancouver study has been completed and indicated that the technology can be used to identify clean trucks as well as high-emission trucks. In particular, the Metro Vancouver pilot study deployed a new remote sensing technique, called the Streamlined, Heavy-duty Emission Test (SHED), which collects exhaust gas samples while a heavy-duty truck is driven through a 50-foot long tent.[38] Metro Vancouver is now considering whether or not to incorporate heavy-duty vehicle remote sensing into its heavy-duty vehicle I/M programme.[39]

Increasing importance of roadside inspection and remote sensing

After-treatment technologies pose new enforcement challenges

Most of the Euro IV and newer diesel trucks and buses are equipped with the Selective Catalytic Reduction (SCR) after-treatment device to meet the NOx emissions requirement, but the use of SCR technology poses new enforcement challenges. To keep the SCR function working as designed, vehicle operators need to regularly replenish urea—a reductant used by the SCR device to convert NOx into nitrogen and oxygen—otherwise NOx emissions are released untreated, and the level of emissions could be much higher than earlier models.

Roadside inspection/ remote sensing programme can indentify vehicles with malfunction after-treatment devices

As the cost of fuelling urea-SCR systems is non-trivial, especially for freight operators who are typically operating at thin profit margins, drivers do not have a clear incentive to properly refill urea. EU and US new vehicle certification requirements call for the incorporation of robust onboard failsafes (such as a driver warning system or vehicle performance degradation) to ensure that drivers properly refill onboard urea tanks with high-quality urea. Roadside inspection/remote sensing, if can be designed to monitor NOx emissions, can serve as another line of defence to catch high NOx emitters and promote proper urea refuelling.

A roadside inspection/remote sensing programme that can monitor PM emissions could also be used to screen vehicles with malfunctioning diesel particulate filters. DPFs are after-treatment devices that can substantially reduce PM emissions from diesel vehicles. Even though DPFs are only required for meeting Euro VI standards for diesel heavy-duty vehicles, many buses and trucks operating in Hong Kong have been retrofitted with DPFs.

2.3.3 Citizens reporting smoky vehicles

The effectiveness of citizen's reports is limied, but it can raise public awareness

Enlisting citizens to report smoky vehicles to the regulatory authority is another way to strengthen the enforcement effort. The effect of this programme on reducing vehicle emissions is limited, however, because citizens can only observe smoke, not invisible pollutants. However, a number of countries/cities have adopted this programme (such as the UK, the Philippines, Santiago in Chile and Hong Kong) as it can raise public awareness.

2.3.4 Raising public awareness

Public awareness is a key to promoting proper maintenance and I/M compliance

Vehicle owners and technicians often pay more attention to vehicle safety and roadworthiness than they do to vehicle emission performance. Raising public awareness could help to promote proper maintenance and I/M compliance and to secure public support. Sufficient funding should be set aside for this effort.

A public awareness campaign should include a focus on at least three elements: i) educating the public and service mechanics on the emissions requirements of the I/M test; ii) publicising the health benefits of the I/M programme; and iii) educating vehicle owners the co-benefits of a well-tuned vehicle in reducing emissions and fuel use. The Greater Vancouver region, for instance, releases an annual report that summarises emissions reduction from the programme as well as other key programme statistics.

To secure strong public support, policy makers should also develop a performance standard for the inspection stations that ensures fair and reliable testing and penalises poor-performing stations.

2.4 Obtaining and managing resources

Sufficient funding should be secured for the sustainable development of I/M programmes

As the above discussion suggests, an effective I/M programme requires investments not only in test equipment and labour for conducting inspections, but in resources for programme oversight and public education. The government should ensure that it appropriates sufficient funds to cover the costs associated with managing, running, and overseeing the I/M operations (including a data management system, audits, equipment calibration, roadside inspections, education campaign, etc.). As the inspection fees are a major source of funding, the full costs of managing and operating the I/M system should be considered when setting/revising the I/M inspection fee structure.[40]

2.5 Never overlook the 'maintenance' in inspection and maintenance

Policy makers should ensure vehicle manufacturers and maintenance sectors are ready for I/M programmes

An I/M programme cannot successfully reduce emissions if high-emission vehicles that are spotted are not properly maintained and repaired. In particular, before enforcing tighter emissions requirements, policy makers should allow sufficient lead time for the service industry to equip itself, including time to get the necessary equipment and ensure that mechanics and technicians are sufficiently trained, so that it can repair the failing vehicles. In addition, policy makers should ensure the quality of replacement parts.

Regulatory agencies could also consider creating a fund to encourage proper maintenance or early retirement of high-emission vehicles. For instance, the Consumer Assistance Programme administered by the California Bureau of Automotive Repair offers car owners a USD1,000-1,500 grant for scrapping a vehicle that fails the emission test, and a USD500 subsidy for low-income residents to repair high-emission vehicles.[41]

As emission control technologies continue to evolve, manufacturers can play an increasingly important role in providing repair training. Policy makers should engage them in designing programmes for continuously upgrading the service industry.

3 Contrasting the Hong Kong Inspection and Maintenance Programme with International Best Practices

3.1 Overview of the Hong Kong I/M programme

Emission test is an element of the annual vehicle examination

In Hong Kong, vehicle emission inspection is one part of the annual safety and roadworthiness testing required for licence renewal. The Transport Department (TD) administers the annual vehicle examination and the Environmental Protection Department (EPD) provides support by establishing the test procedure and standards.

Vehicle examination is conducted at government-owned and private test centres

Annual emission testing is conducted in test-only centres and test-and-repair centres. The government established four test-only centres which perform roadworthiness inspections and emission tests for commercial vehicles (taxis, commercial light buses, trucks and coaches). Of these four facilities, three are run by the TD and one is operated by a TD contractor. In addition, the TD commissions and certifies 22 privately owned test centres (Designated Car Testing Centres; DCTCs) that conduct annual inspections for private passenger cars. All of the 22 DCTCs repair vehicles and perform roadworthiness and emission tests.[42] As far as franchised buses are concerned, inspections and emission tests are performed at the bus depots, where TD vehicle testers are posted on site to conduct roadworthiness and emission inspections.

3.1.1 Hong Kong I/M test procedures, cut points and frequency of inspection

Annual vehicle emission tests are mainly unloaded tests

The emission tests conducted at the TD test centres and DCTCs are primarily unloaded tests. Idle/fast idle (plus the lambda test[43] for post-1991 models) are used to measure CO emissions from gasoline light vehicles, idle/fast idle tests are conducted to measure the CO and HC emissions of LPG vehicles, and free acceleration tests are used to measure smoke from diesel vehicles. Ten per cent of the diesel vehicles presented for roadworthiness inspection are randomly selected to undergo loaded Lug-down tests on a chassis dynamometre, following the test procedure specified by the EPD. Franchise buses are not selected for conducting the Lug-down test because the bus depots are not equipped with chassis dynamometres.

In parallel with the annual emission tests, the EPD runs a Smoky Vehicle Testing Programme which uses the Lug-down test to check the smoke level of suspected smoky diesel vehicles (discussed below).

Pass/fail criteria are comparable to those adopted in EU and Japan

Table 3 lists the test procedure and pass/fail criteria of all the emissions tests administered by the TD and the EPD, together with those adopted in the EU for gasoline and diesel vehicles for comparison. The test procedures of the annual emission tests for gasoline and diesel vehicles essentially follow the European directive on the roadworthiness test; the test procedure for LPG vehicles follows the Japanese regulation.[44]

The pass/fail criteria of the emission tests vary by vehicle age (hence the emission level) and also by age for diesel vehicles. The pass/fail criteria are generally the same as those in the European requirements for pre-Euro 3 gasoline vehicles, but are less stringent for Euro 3 and newer gasoline vehicles. The stringency of the emission test for diesel vehicles is comparable to that of the European programme.

All commercial vehicles in Hong Kong must go through a pre-registration examination and a roadworthiness test annually thereafter. Private cars below the age of seven years are exempted from the annual roadworthiness test, and are required to pass the test every year after they reach the age of seven.

No data available on emission test failure rates

From 2007-11, on average five to six per cent of all private and commercial vehicles failed the annual inspection test (i.e. failed any one part of the tests on emissions, roadworthiness and fitness),[45] but there is no data on the per cent of failure that is attributed to failure of the emission requirements alone

Table 3: Hong Kong in-use vehicle emission test method and standards

Vehicle type/ share of vehicle stock	Emission test method	Date of manufacture	Emission standards	Vehicles tested in 2011[d]	Responsible department
HONG KONG					
Gasoline vehicles	Exempt	Before 1 Jan 1975	N/A	N/A	N/A
	Idle/fast idle	1 Jan 1975 to 31 Dec 1986	CO <= 4.5%	286,382[e]	Transport Department
		1 Jan 1987 to 31 Dec 1991	CO <= 3.5%		
	Idle/fast idle, Lambda	On or after 1 Jan 1992	Idle: CO <= 0.5% Fast idle: CO <= 0.3% Lambda: 0.97-1.03		
LPG vehicles	Idle	All	CO <= 1.0% HC <= 300 ppm		
Diesel commercial vehicles (DCV)[a]	Free acceleration	GVW > 5.5 tonnes, and manufactured before 1 Jan 1990	Smoke <= 60 HSU, or light absorption <= 2.13m^{-1}	117,027[f] (of which 5.452 are franchise buses)	
		All other DCVs	Smoke <= 50 HSU or light absorption <= 1.61 m^{-1}		
10% sample of DCVs presented for I/M test [b,c]	Lug-down	GVW > 5.5 tonnes, and manufactured before 1 Jan 1990	Smoke <= 60 HSU, or light absorption <= 2.13 m^{-1}	~ 11,000[g]	
DCVs identified as smoky vehicles [b,c]		All other DCVs	Smoke <= 50 HSU or light absorption <= 1.61 m^{-1}	<10,000	Environmental Protection Department
EUROPEAN UNION					
Gasoline vehicles	Idle	Not controlled by catalytic converter — Put into service on or before 1 Oct 1986	CO <= 4.5%		
		Not controlled by catalytic converter — Put into service after 1 Oct 1986	CO <= 3.5%		
	Idle/ Fast Idle	Controlled by catalytic converter — Pre-Euro 3 (TA before 1 Jan 2000)	Idle: CO <= 0.5% Fast idle: CO <= 0.3% Lambda: 0.97-1.03		
		Controlled by catalytic converter — Euro 3 or newer	Idle: CO <= 0.3% Fast idle: CO <= 0.2% Lambda: 0.97-1.03		
Diesel vehicles	Free acceleration	Naturally aspirated	Light absorption <= 2.5 m^{-1}		
		Turbocharged	Light absorption <= 3.0 m^{-1}		
		Euro 4/IV or newer light-duty and heavy-duty vehicles, and EEV	Light absorption <= 1.5 m^{-1}		

Sources:
Road Traffic (Construction and Maintenance of Vehicles) Regulations of Hong Kong, Cap 374A — Section 9.
European Council Directives 2009/40/EC and 2010/48/EC.

Notes:
a. The opacity test standards are set in Hartridge Smoke Units (HSU) and absolute units of light absorption (m^{-1}).
b. The setup of the dynamometre makes it difficult to undergo Lug-down tests for front-wheel drive vehicles; also, Lug-down tests cannot be conducted on vehicles with anti-lock brakes (ABS). For these two vehicle categories, free acceleration opacity tests are conducted.
c. In order to check if engines are tuned for low power for the purpose of passing the opacity test, measured power at wheels is also checked during the Lug-down test; the vehicle will fail the test if the measured power at wheel is lower than half of the specific engine power.
d. Based on data from the Transport Department Annual Transport Digest (only counts first inspection); number of vehicles tested under the Smoky Vehicle Programme is provided by the EPD.
e. The number of gasoline and LPG vehicles inspected combined.
f. Includes a small number of gasoline goods vehicles (~1,000 vehicles) as the data in the Annual Transport Digest are not broken down by fuel type.
g. Assumes ten per cent of the goods vehicles tested (excluding franchise buses) are selected to undergo the Lug-down test.

3.1.2 Compliance promotion and enforcement

To renew vehicle registration, the in-use vehicle emission test has to be passed

Any in-use vehicle in Hong Kong, with the exception of new passenger cars which are six years old or newer, must pass the in-use vehicle emission requirements (as a part of the annual roadworthiness test) for licence renewal.[46] Linking the annual vehicle examination with licence renewal appears to be effective in terms of forcing vehicle owners to repair their vehicles prior to the annual examination and submit them for emission tests.

EPD's roadside inspection and spotter programme help to identify on-road smoky diesel vehicles

Since 1988, the EPD has been operating a Smoky Vehicle Control Programme to monitor the exceeding of emissions of diesel vehicles in between vehicle inspections. The programme comprises a volunteer spotter programme and roadside operation.

The EPD recruits volunteer spotters and trains them to spot and report smoky vehicles on the road. Once a smoky diesel vehicle has been reported to the EPD by an accredited volunteer spotter, the vehicle owner has to present the suspected smoky vehicle to one of the six EPD accredited Vehicle Emission Testing Centres (VETC) for a Lug-down smoke test within 12 working days.[47] If a vehicle fails the Lug-down test, it needs to be fixed and retested, otherwise the vehicle's registration will be revoked.

Another programme to enforce the I/M requirements for diesel vehicles is the roadside smoke testing operation, jointly organised by the EPD and the Police Department. Organised eight to 10 times every month, the roadside inspection can deter any 'clean for the day' fix, and can also spot vehicles having failures between inspections, which can cause high emissions.

During the roadside operation, the police stop vehicles with excessive visual emissions for a free acceleration opacity test at the roadside. The owner of any vehicle which fails the smoke test will be fined HKD1,000. As with the Smoky Vehicle Control Programme, the owners of vehicles failing the roadside test are required to rectify the emission problem and present their vehicles at an EPD-accredited Vehicle Emission Testing Centre to undergo a Lug-down test within 12 working days.

Of the high-emission diesel vehicles that are identified by volunteer spotters and during roadside inspections to undergo Lug-down tests, more than 70 per cent passed the test in the first inspection in 2011.[48]

3.1.3 Quality assurance

a) Annual vehicle examination

Audits for private vehicle test centre are organized and conducted by TD.

The TD is responsible for overseeing annual vehicle examination conducted by the DCTCs. The TD has a monitoring team that monitors the performance of DCTCs, and each is audited at least once a week. During the audits, TD monitoring teams observe how the roadworthiness tests and emission tests are conducted and carry out random checks on the correctness of the data entered in the computer. For the four Government-owned vehicle examination centres, the TD manages their operations the same way as its own facility.

Emission test results are largely reported by manual processes

At all the vehicle examination centres, the analysers and opacimetres (instruments that measure exhaust gas opacity) used to conduct the emission tests automatically generate a paper slip with the test results (CO concentration and lambda value for gasoline cars, CO and HC concentration for LPG vehicles, and smoke level for diesel vehicles). After an emission test is completed, a vehicle tester reviews the emission test result slip and manually marks down the emission pass/fail results on the vehicle annual examination report according to the emission standards. The tester then attaches the emission result slip to the examination report of the inspected vehicle. Every day, the vehicle testers manually input test results for gasoline and LPG vehicles into computers on site for transmission to TD's central server. Test results for diesel vehicles do not have any electronic records. DCTCs are required to keep all the vehicle examination reports on site for one year for auditing purposes.

Lug-down tests are conducted in a semi-automated manner.

The results from the Lug-down tests conducted for ten per cent of the diesel vehicles are stored in the computers on site. The computer is programmed to print out a Lug-down test report automatically that includes the pass/fail decision every time a test is completed, so the vehicle testers do not need make any judgment. The paper test reports are included in the vehicle annual examination report of the vehicle being tested.

The computer programme operating the Lug-down test has been set up to run a calibration module for the dynamometre and the opacimetre when the computer is turned on in the morning. Regular inspection and maintenance of the Lug-down test dynamometres are performed by the manufacturers of equipment.

b) Smoky Vehicle Control Programme

At the VETC managed by the EPD, the same computer programme is used for conducting the Lug-down test. A Lug-down test report, which includes a pass/fail decision, is automatically generated by the computer after a vehicle is tested, and all the test reports are faxed to the EPD in one batch once per day for record (see Figure 2).

Equipment are auditted regularly

The EPD conduct surprise visits to audit each accredited VETC at least once every quarter.[49] Calibration of dynamometres and opacimetres is performed first thing every morning by the computer software the same way as in the TD centres. Regular inspection and maintenance of the dynamometres are reportedly performed once per year by the manufacturers.

Figure 2: The dynamometre and the computer used for conducting the Lug-down test at VETC in Yuen Long

3.1.4 New test requirements for gasoline and LPG light vehicles

A new transient test, The Hong Kong Transient Emission Test, will be introduced in 2014...

In light of new findings showing that LPG taxis and light-buses contribute to significant amount of urban pollution (39 per cent of NOx and 55 per cent of HC emissions in urban corridors), in 2013/14 the EPD will launch a new remote sensing roadside programme targeting high-emission in-use gasoline and LPG light-duty vehicles. In parallel, the EPD will gradually replace the idle/fast test for all gasoline and LPG vehicles with a new transient test called the Hong Kong Transient Emission Test (HKTET). The HKTET has been developed to check HC, NOx, CO and CO_2 emissions as well as the lambda value of the test vehicles. The test will be enforced on commercial LPG vehicles as well as all light gasoline vehicles.[50]

together with remote sensing for gasoline and LPG light vehicles

The remote sensing technology to be deployed by the EPD can spot and record light vehicles with high HC, NOx, CO and CO_2. The owners of the identified high-emission vehicles will be informed and advised to take their vehicles to the EPD-designated emission testing centres to undergo the HKTET within 12 working days. As with the Smoky Vehicle Control Programme, if a spotted vehicle fails the HKTET it needs to be repaired and retested until the vehicle passes the test, otherwise its registration will be revoked.

HKTET aims to target vehicles with high emissions

Based on the remote sensing data collected by the EPD, the pass/fail points for the HKTET tests are set at twice the corresponding new vehicle emission standards.[51] Hence, vehicles that are designed and manufactured to meet stricter new vehicle standards face more stringent in-use emission requirements. The EPD's analysis suggests that the HKTET correlates well with the NEDC test cycle (the type approval test cycle for European standards),[52] and the EPD believes that the standards thus set would be sufficiently stringent to screen for vehicles suffering from engine breakdown, which greatly increases emissions, and at the same time allow for a sufficient margin for increased vehicle emissions caused by normal engine aging and the associated wear and tear of the vehicles' mechanical parts.[53]

Before launching the HKTET, the EPD is arranging a series of seminars to introduce the new test, and is organising workshops for the vehicle maintenance trade to discuss methods of properly maintaining LPG vehicles.[54]

3.2 Observations

- *The announced plan to upgrade the inspection programme for gasoline and LPG light vehicles could significantly improve the effectiveness of the I/M programme.*

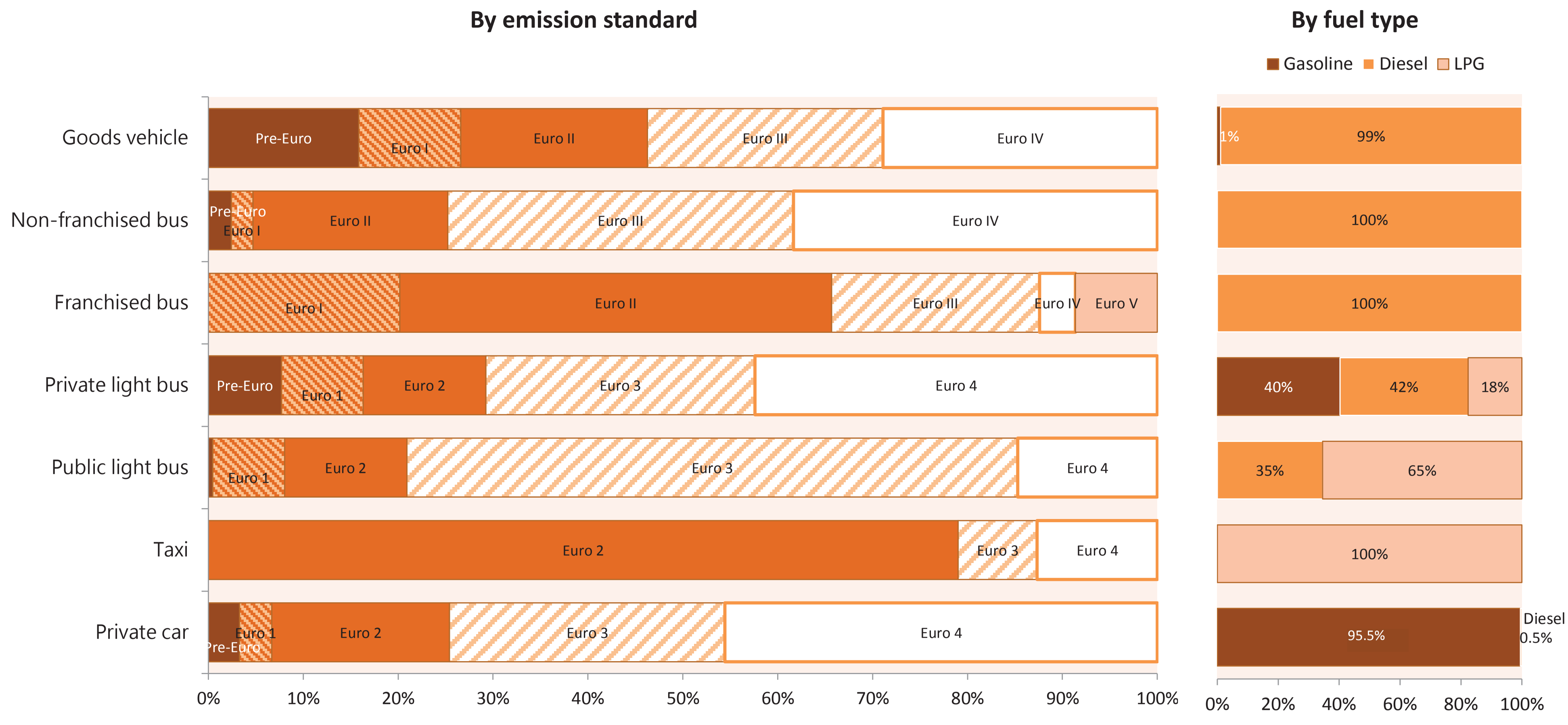
Current emission tests pay less attention to gasoline and LPG light vehicles

The majority of gasoline and LPG light vehicles operating in Hong Kong are Euro 1 and more advanced vehicles (see Figure 3), hence almost all of the cars, light buses and taxis are now electronically controlled. As discussed in Section 3, the unloaded tests (idle test and idle/high idle test) that have long been used for annual inspections are not effective for the detection of excessive emissions from electronically controlled vehicles. This suggests that the annual inspections have very limited effect on catching high-emission light-duty gasoline and LPG light vehicles. In addition, gasoline and LPG vehicles have never been subjected to any roadside emission inspection efforts.[55] As a result, 80 per cent of LPG taxis and 45 per cent of LPG public light buses have been found to be operating with failed catalytic converters and with emissions essentially uncontrolled, but are not being caught during the annual inspections.[56] With private cars, taxis and light buses together responsible for nearly half of the city's CO emissions and seven per cent of NOx emissions (see Figure 4), better emission testing programmes should be devised and put in place.

New transient test for LPG and gasoline vehicles is a significant improvement

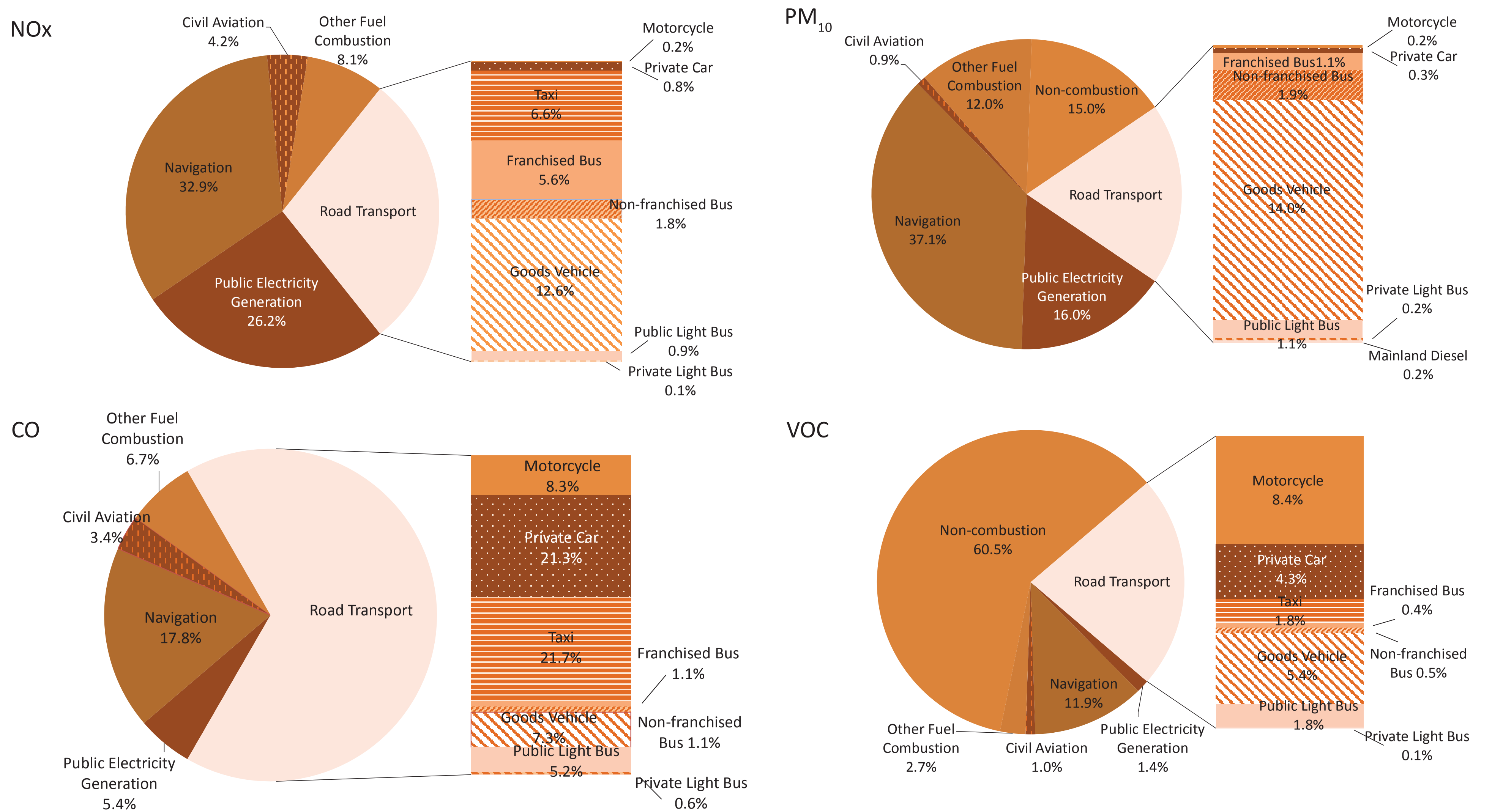
By measuring CO, NOx and HC emissions under a loaded test cycle, the proposed new HKTET for gasoline and LPG vehicles could substantially improve the capability of annual vehicle examination in detecting high emitters. By implementing in parallel the proposed remote sensing inspection programme targeting gasoline and LPG vehicles, the government should be able to effectively deter attempts to perform 'clean for the day' repairs, such as replacing a failed catalyst with a new one prior to inspection and exchanging it back afterwards. The remote sensing programme, which provides year-round surveillance, can also identify vehicles with high emissions which are caused by an emission controls breakdown between inspections, and can bring those vehicles to proper repairs as early as possible. In the longer term, the remote sensing data could also be used to assess the effectiveness of the I/M programme.

Figure 3: Share of licensed vehicles by emission standard and fuel type (2011)



Source: Communications with EPD (May 2013).

Figure 4: Contribution of emissions by sector and vehicle type (2011)



Sources:
Communications with EPD (May 2013);
EPD (2013), '2011 Hong Kong Air Pollutant Emission Inventory', http://www.epd.gov.hk/epd/english/environmentinhk/air/data/emission_inve.html, accessed 10 May 2013.

- *The Free Acceleration Smoke test and the Lug-down test are not designed to screen PM and NOx emissions from diesel vehicles; a new test programme is urgently needed for the effective control of diesel vehicle emissions.*

New tests for measuring NOx and PM from diesel vehicles are urgently needed

The city's diesel commercial fleet (cargo vehicles, buses and a third of private light buses) emits about one fifth of the NOx and PM emissions in Hong Kong, so these vehicles should be a top priority within Hong Kong's I/M programme. The Free Acceleration Smoke test and the Lug-down test now being used for diesel vehicle testing are both designed for older (pre-Euro III) engines, using smoke as a surrogate for PM. These tests are not effective for screening emissions from the growing number of Euro III and newer diesel vehicles. Also, as explained in Section 2, vehicle smoke and PM/NOx emissions have a very poor correlation, so these tests cannot effectively measure PM and NOx emissions. New tests or a new approach to screening NOx and PM emissions from diesel vehicles should be devised.

- *Quality assurance should be improved to enhance the credibility of the I/M programme.*

Automated process can greatly facilitate quality control

The emission testing conducted during the annual vehicle examination relies heavily on vehicle testers to correctly record the pass/fail decision onto inspection reports and to input it into computers. The largely manual process of recording the test results is susceptible to human errors and manipulation. And while the monitoring team of TD visits each DCTC at least once a week to inspect the performance of testers and randomly check the accuracy of the examination data entered into the computer, some areas of the examination report can be difficult to validate. For example, at some of the DCTCs the emission result slips automatically generated by the analysers do not show the vehicle licence number; in the absence of the vehicle licence number,[57] there is no easy way to validate whether the result slip attached to the vehicle examination report actually reflects the emission performance of the vehicle being examined. The Lug-down test procedure, which was introduced later, is much less prone to error or fraud by automating the pass/fail decision and by generating emission test reports that contain vehicle-specific information (e.g. Emission Testing Notice Number).

With respect to the auditing of the performance of DCTCs, the government-owned test centres and individual vehicle testers, the emission test results could have been a set of valuable data for directing monitoring and auditing efforts. However, only some emission test data are currently collected electronically (results from emission tests on gasoline and LPG vehicles and Lug-down tests), and it appears that these data have not been systematically used to audit the performance of the test centres or individual vehicle testers.

- *Upgrading the light vehicle inspection programme with the new transient test for gasoline and LPG vehicles may require substantial capital investment.*

Upgrading to the new transient test requires significant investment

While the new transient test, the HKTET, is much more effective for screening out high-emission gasoline and LPG vehicles, the test takes much longer to run than the current idle/fast idle test (up to 30 minutes vs less than 10 minutes), and requires the use of more advanced emission analysers and dynamometres.

TD statistics suggest that more than 286,000 light vehicles (including private cars, taxis and light buses) went through an annual vehicle examination in 2011.[58] Assuming that each set of the HKTET takes 25 minutes to complete, and each test centre operates 10 hours a day and 5.5 days a week, about 42 sets of dynamometre and associated test equipment will be needed to inspect 286,000 vehicles each year. Therefore, a substantial upfront investment for upgrading test equipment will be needed if all gasoline and LPG light vehicles are to be subject to the transient test.

4 Recommendations

Based on a review of international best practices, the following recommendations are offered as steps towards the improvement of Hong Kong's current I/M programme:

- *Develop and adopt new I/M tests for diesel vehicles that measure PM, NOx and other important diesel vehicle emissions.*

Better tests for diesel vehicles must be a priority going forward

The poor correlation between vehicle smoke and PM/NOx emissions suggests that the current I/M tests for diesel vehicles (Free Acceleration opacity test and Lug-down opacity test) cannot serve well the purpose of identifying diesel vehicles with excessive NOx and PM emissions. A new test that measures PM and NOx emissions directly, or other emissions which correlate better with these pollutants (e.g., carbon monoxide as a predictor of PM)[59] should be developed. The new test should also be able to measure pollutants generated from the use of advanced emissions control technologies, such as NO_2 (from the use of DOC) and ammonia (from the use of SCR). Whatever tests are adopted should be conducted under a loaded condition to enable NOx measurement. In addition, the new programme should include a roadside test or remote sensing element that monitors PM and NOx emissions from heavy-duty vehicles in order to induce proper refuelling of urea for vehicles equipped with SCR systems and regular repair of DPF-equipped vehicles.

Leverage ongoing research abroad and technical expertise in research institutes

Research is now under way in Europe, China, Canada and the US to explore the feasibility of using tailpipe testing and/or remote sensing technology to measure PM, NOx and other invisible pollutants from in-use diesel vehicles. Australia has developed a transient I/M test (DT80) for diesel vehicles, and a study for the Thai government has also introduced steady-state loaded tests for diesel vehicles.[60] The SHED test developed by the University of Denver also offers a promising way to measure diesel vehicle emissions under loaded conditions. The government should monitor these new developments closely, and establish regular communications and exchange with other government agencies (e.g. those in Australia, Los Angeles, Vancouver, Thailand, Beijing city and mainland China) to ensure the latest research undertaken abroad can effectively inform its own efforts.

As a substantial amount of testing would be needed to develop a new test cycle and standards, or to verify the effectiveness of remote sensing technology, the government should leverage resources in Hong Kong's universities and research institutes to support this effort. The Heavy Vehicles Emissions Testing and Research Centre at the Institute of Vocational Education (IVE) Tsing Yi campus is reportedly collaborating with the EPD to identify an emission testing procedure which can replace the Lug-down test.[61] Similar joint efforts could be launched in terms of research into the use of remote sensing/roadside testing technologies for diesel vehicles.

- *Improve quality control and audit.*

Sufficient funding and multi-agency collaboration are needed for good quality control and audit

Experiences from industrialised and developing countries suggest that I/M programmes can often be associated with fraud and corruption. The credibility and effectiveness of an I/M programme can be seriously compromised if the government fails to deter corruption and the evasion of regulation. While the quality assurance practices discussed in Box 2 may be more suitable for developing countries, some measures could be considered for use in Hong Kong. In addition, sufficient funding should be allocated and cross-agency collaboration should be secured in order to establish an effective quality control and audit programme.

Among the measures recommended in Box 2, the government could prioritise improvements to the following areas:

Automated system, detailed data analysis and targeted enforcement can greatly enhance quality control

1. Establishing a computer and data system that can generate fully automated pass/fail decisions and transfer emission test data, access data and calibration data real time to a centralised database controlled by an overseeing government body;

2. Developing a data analysis programme that can automatically perform detailed analysis of test data, including comparison of test results between centres, test lanes and vehicle testers, and flagging of anomalies for further investigation;

3. Conducting surprise audits of vehicle test centres; the audits could more frequently target test centres where abnormal test data are found;

4. Conducting regular audits of all test equipment to ensure consistent test results across all the test lanes and centres; the audit could be carried out by an independent ISO-certified materials standards laboratory; and

5. Certifying all test personnel, and establishing a system in which testers who have been dismissed because of malpractice cannot be hired in other test centres.

- *Phase in the switch to gasoline/LPG vehicle dynamometre testing, and evaluate the cost-effectiveness of exempting clean private cars.*

Target new transient tests on commercial vehicles to maximise cost effectiveness

As discussed earlier, the switch to transient testing for all gasoline and LPG light vehicles could mean substantial upfront investment in upgrading testing equipment and training vehicle testers would be needed if all gasoline and LPG light vehicles were to be subject to this test at the outset. The EPD could consider phasing in the test to first target commercial vehicles, such as taxis and light buses, as these are driven significantly more than private cars.[62]

Identify subset of clean private cars that can be exempted from the new test

Using the remote sensing data collected to date, the EPD may investigate the practicality of exempting some private gasoline cars that are identified 'clean' from undergoing the new transient test and assess the emission reductions that may be foregone. The expanded exemption could be done by setting up a clean screen programme, adjusting the age by which cars must undergo annual emission tests, or allowing cars identified 'clean' to be tested less frequently. As an example, the clean screen programmes in the US often assume that a vehicle which has repeated remote sensing readings within a certain period (e.g. two or three clean readings within a 10-month window before registration renewal) is clean, and allow registration renewal without the need to undergo a tailpipe test. The clean screen programmes in the State of Virginia and Colorado have been implemented for years and may offer some useful lessons to Hong Kong when designing such programme.

By exempting the cleanest fraction of the fleet from undergoing the transient test, the government could reduce the infrastructure and labour costs needed for implementing the new test, while not compromising too much emission reduction benefits.

- *Strengthen collaboration between government agencies, including the EPD, TD, EMSD and other government agencies, and clearly define the role and responsibilities of each agency.*

Multi-agency collaboration is a key success factor

Various government agencies are involved in the operation of Hong Kong's I/M programme: the TD oversees the annual examination of vehicles, including emission testing; the EPD manages roadside and remote sensing testing, oversees the test centres that test the suspected smoky vehicles, and develops the testing procedure and standards; the EMSD administers the Voluntary Registration Scheme for Vehicle Mechanics; and the Vocational Training Council offers training for vehicle mechanics. Each of these tasks is critical to the success of the I/M programme.

Collaboration among the agencies should be strengthened and the role of each agency should be clearly defined so that important programme elements, such as quality assurance, audits, and the training of vehicle testers and vehicle repair mechanics when new emission test programmes are introduced, can be undertaken smoothly and effectively.

- *Build public and political support through educating the public and elected officials on the health benefits of an upgraded I/M programme.*

Public education is needed to publicise I/M programme benefits

Public perception on effectiveness, transparency and fairness of the I/M programme will affect the public's confidence and willingness to cooperate. Ensuring broad public support would also help government agencies to secure the funding needed for upgrading the programme as discussed above. The government could consider establishing an ongoing education programme to inform the public of the benefits of I/M programmes and to demonstrate that the programme is fair and effective. A useful example is the AirCare Vehicle Emissions Testing Program for the Greater Vancouver region, which publishes annual reports on its website, providing inspection statistics and estimated emissions benefits.[63]

5 Conclusion

An effective I/M programme ensures that benefits from other vehicle programmes are realised

Experiences from big cities that were once plagued by serious air pollution, such as Los Angeles, demonstrate that concerted efforts to combat air pollution could make significant progress towards cleaning the air. It is encouraging to see the unveiling of the Clean Air Plan for Hong Kong, which shows a serious commitment by the Hong Kong government to reducing air pollution from local and regional sources. Several initiatives on controlling vehicle emissions have been proposed, but a well designed and effectively enforced I/M programme is needed to ensure that, whatever measures undertaken on reducing vehicular emissions — be it enforcing new vehicle standard, retrofitting or replacing emission control devices, or the accelerated replacement of old and dirty trucks — the promised environmental and health benefits can be realised.

New emission tests are needed to target different pollutants and vehicle types

The proposed upgrade of in-use emission tests for gasoline and LPG vehicles is an important step towards cleaning up in-use vehicles. The new dynamometre testing and remote sensing inspection programme for gasoline and LPG vehicles, coupled with the upcoming effort to replace the catalytic converters of LPG taxis and minibuses, should be able to effectively reduce and continuously track pollution from gasoline and LPG light vehicles. To further enhance the I/M programme, more would need to be done in terms of improving the testing of diesel commercial vehicles, enhancing quality control and assurance, educating the public about the benefits of the programme, and strengthening cross-agency cooperation.

Further tightening of vehicle standards is also needed

A successful I/M programme is no doubt an important and necessary measure in terms of keeping the emissions of the in-use vehicle fleet from worsening, but I/M alone is not sufficient to bring total vehicle emissions down unless new vehicles are getting cleaner over time. The government should strive to adopt, as early as possible, world-class new vehicle emission standards, such as Euro 6/VI standards, and/or California LEV 3 requirements for light vehicles. These new standards not only tighten emission limits, they also impose stricter durability requirements which forces manufacturers to prodcue more durable emission control devices.

Achieving clean air is attainable

Achieving clean air will take years of work but, with an effective vehicle emission control programme in place, and the joint efforts of multiple bureaux and departments to gradually roll out the various policy measures proposed in the Clean Air Plan, the goal of gradually improving the air quality of Hong Kong is attainable.

Endnotes

1. To encourage the use of ultra-low-sulphur fuel, the government reduced the fuel tax on 10-ppm sulphur diesel to $0.56/litre on 1 December 2007; on 14 July 2008, the government waived the fuel duty for 10-ppm sulphur diesel. In response to these government incentives, oil companies have voluntarily switched over to supplying 10-ppm sulphur diesel since December 2007, even though the 10 ppm sulphur limit came into play more than two years later, on 1 July 2010. Switching to lower sulphur content has demonstrated health benefits, not only because SOx emissions directly generated from the engine combustion process would be lowered, but also because ultra-low-sulphur fuel (with <10-ppm sulphur) enables the use of the best and most effective emissions control equipment on vehicles, such as diesel particulate filters.

2. See EPD (2013), 'Cleaning the Air at Street Level', http://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/cleaning_air_atroad.html, accessed 20 April 2013.

3. National Research Council (2001), *Evaluating Vehicle Emissions Inspection and Maintenance Programs,* the National Academy Press, http://www.nap.edu/catalog.php?record_id=10133, accessed 15 April 2013.

4. Hong Kong Environment Bureau (2013), *A Clean Air Plan for Hong Kong*, March, http://www.enb.gov.hk/en/files/New_Air_Plan_en.pdf , accessed 27 July 2013; Hong Kong Transport Department (2012), *The Annual Traffic Census - 2011*, p.38, June, http://www.td.gov.hk/filemanager/en/content_4568/annual%20traffic%20census%202011b.pdf, accessed 24 July 2013.

5. PA Government Services. (2004), Vehicle Inspection and Maintenance Programs: International Experience and Best Practices. *A Report for the Office of Energy and Information Technology*, US Agency for International Development (USAID), http://pdf.usaid.gov/pdf_docs/PNADB317.pdf, accessed 15 April 2013; Walsh, M P (2005), *Motor Vehicle Inspection and Maintenance: The Worldwide Experience*, http://www.walshcarlines.com/pdf/SIAT2005%20IM.pdf, accessed 15 April 2013.

6. Ibid.

7. Weaver, C and Chan, L (2003), *Sri Lanka Vehicle Emissions Control Project – Revised Final Report*, prepared for the Ministry of Environment, Government of Sri Lanka, cited in PA Government Services (2004)

8. See note 5, PA Government Services (2004), op. cit.

9. AirCare website: http://www.aircare.ca/ , accessed 15 April 2013; See also note 5, PA Government Services (2004), op. cit.

10. GTZ (2005), *Inspection & Maintenance and Roadworthiness*. July. http://www.sutp.org/component/phocadownload/category/43-4b?download=74:4b-im-en, accessed 15 April 2013.

11. For more information on different types of short tests developed for I/M programmes, see Samaras, Z and Zachariadis, T (1995), *The inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency, Detailed report 1 – Review of short tests*. Thessaloniki: Aristotle University, LAT Report 9502, http://ec.europa.eu/environment/archives/pollutants/inusecars1.pdf, accessed 15 April 2013.

12. For cars with electronic fuel injection and ignition management systems, excess emissions are more likely related to malfunction sensors or a degraded catalyst, as opposed to misfires or simple maladjustments. Emission control defects of Euro 1 or newer cars may therefore not be detected by measuring pollutants at idle. For instance, an EU study found that idle/fast idle test could only identify 15 per cent of the high-emission-three-way-catalyst-equipped vehicles. See European Commission (2000), T*he Auto-Oil II Program – A report from the services of European Commission*, p.97. http://ec.europa.eu/environment/archives/autooil/pdf/auto-oil_en.pdf , accessed 15 April 2013.

13. The transient loaded test needs to be conducted using more sophisticated and expensive testing equipment, including a constant volume sampler (CVS) and a laboratory-grade analyser that collects and calculates average emissions during the entire tests, and a multiple-curve dynamometre with flywheels that mimics instantaneous load changes and the power needed to accelerate the inertial masses of the test vehicles. Therefore, the labour costs and testing equipment costs of conducting a transient loaded test could be far higher than those of a steady loaded test. In addition, the test vehicle needs to be tied onto the dynamometre before the test, so the whole test takes longer. See also note 11, Samaras, Z and Zachariadis, T (1995), op. cit.

14. Communications with Dave Sosnowski of US EPA (16 May 2013). The Clean Air Act (CAA) requires areas with serious ozone pollution and an urban population of 200,000 as of 1980 to achieve reductions in NOx (unless it is demonstrated that NOx reductions do not help reduce ozone in that area) and implement enhanced I/M programmes (with some form of loaded testing) for vehicles that are not equipped with OBD. In addition, the CAA requires all areas implementing I/M programmes to incorporate OBD testing for 1996 or newer light-duty vehicles.

15. Communications with Dave Sosnowski of US EPA (16 May 2013).

16. See notes 5 and 10, Walsh (2005), op. cit.; PA Government Services (2004), op. cit.; GTZ (2005), op. cit.

17. See McGlothlin, M (2010), 'Nine States that Require Diesel Emissions Tests', *Diesel Powe*r, June, http://www.dieselpowermag.com/tech/1006dp_nine_states_that_require_diesel_emissions_tests/, accessed 17 May 2013; CITA et al. (2011), *TEDDIE— A New Roadworthiness Emission Test for Diesel Vehicles involving NO, NO_2 and PM measurements*, 7 December, http://www.cita-vehicleinspection.org/LinkClick.aspx?fileticket=XsD3f1wuKxQ%3D&tabid=458, accessed 15 April 2013.

18. See note 17, CITA (2011), op. cit.

19. Communications with John Rogers of the Sustainable and Emissions Services Company (26 March 2013).

20. Erlansson, L and Walsh, M P (2003), *Motor vehicle inspection in the national capital region of India: Recommendations for short-, medium- and long terms*, 7 March, http://www.walshcarlines.com/pdf/delhi_im_report.pdf , accessed 15 April 2013; McCormick, R et al. (2003), 'Quantifying the Emissions Benefits of Opacity Testing and Repair of Heavy-duty Diesel Vehicles', *Environmental Science &Technology*, Vol. 37, No. 3, pp.630-637, http://www.arb.ca.gov/enf/hdvip/emission_benefits.pdf , accessed 15 April 2013; Norris, J O W (2005), *Low emission diesel research CP17/18/770: Phase 3 – repor*t. *Report AEAT/ENV/R/1873/Issue 1*. AEA Technology – Environment, Didcot, UK.

21. See note 20, McCormick, R et al. (2003), op. cit.; Campbell A (2006), *Vehicle Emission Pilot Project for Diesel Vehicles, a report for the Ministry of Transport of New Zealand*, http://www.transport.govt.nz/research/Documents/06-09-30-Final-diesel-report.pdf, accessed 15 April 2013.

22. Australia Department of Environment and Conservation (undated) *DT80 Test*, http://portal.environment.wa.gov.au/pls/portal/docs/PAGE/DOE_ADMIN/FACT_SHEET_REPOSITORY/TAB1144234/DT80%20TEST.PDF , accessed 15 April 2013.

23. See note 17, CITA (2011), op. cit.

24. Communications with Beijing Institute of Technology (18 April 2013), and Beijing Vehicle Emissions Management Centre (22 April 2013).

25. See US EPA (updated), 'Heavy Duty Vehicles', http://www.epa.gov/obd/regtech/heavy.htm, accessed 2 June 2013.

26. Right now, only 15 states in the US are doing some form of tailpipe testing; these are typically states with a larger share of non-OBD equipped vehicles, so the need to conduct tailpipe tests remains.

27. For instance, the emission standards for an ASM tailpipe test are typically 5-10 times higher than certification standards.

28. California Air Resources Board (CARB) (2009), *Transitioning Away from Smog Check Tailpipe Emission Testing in California for OBD II Equipped Vehicles*, March, http://www.arb.ca.gov/msprog/smogcheck/march09/transitioning_to_obd_only_im.pdf, accessed 15 April 2013.

29. Communications with Dave Sosnowski of US EPA (17 April 2013).

30. See note 17, CITA (2011), *op. ci*t, Some issues with EOBDs include: i) reliability and accuracy of sensors used for EOBD measurements are too low, so EOBD tests are less sensitive than tailpipe tests; ii) EOBD thresholds are set too high to effectively report emissions-related defects, iii) EOBD fails to identify high-emission cases as it only monitors functionality of discrete emission control systems, and iv) EOBD fails to detect malfunctions of equipment that are not controlled by the engine control unit (like DOCs)

31. See note 28.

32. Communications with Leo Carroll and Haskins Hobson of PARSONS (24 April 2013).

33. See note 5.

34. Communications with EPD (20 May 2013). Taxis, public light buses and franchised buses on average travelled 144,000 km, 101,000 km and 76,200 km in 2011 respectively, compared to around 10,000 km for private cars.

35. US EPA (1996), *User Guide and Description for Interim Remote Sensing Program Credit Utility, Office of Air and Radiation*, Office of Mobile Sources, Report EPA420-R-96-004, September; US EPA (1998), *Program User Guide for Interim Vehicle Clean Screening Program Credit Utility*. Office of Air and Radiation, Office of Mobile Sources, Draft Report EPA420-P-98-007, April 1998; US EPA (2004), G*uidance on Use of Remote Sensing for Evaluation of I/M Program Performance*, Office of Air and Radiation, Office of Mobile Sources, Report EPA420-B-04-010, July 2004.

36. Communications with Vescio Niranjan of Envirotest (April 26, 2013). For more information about the remote sensing programmes, see http://aircarecolorado.com/rapidscreen/, http://www.deq.state.va.us/Programs/AirCheckVirginia/ForMotoristsVehicleOwners/OnRoadEmissionsProgramFAQ.aspx, http://law.onecle.com/texas/health/382.204.00.html, http://www.moga.mo.gov/statutes/c600-699/6430000303.htm, http://www.bjepb.gov.cn/portal0/tab189/info9277.htm, http://www.arirang.co.kr/News/News_View.asp?nseq=145717, accessed 5 May 2013.

37. Communications with Beijing Vehicle Emissions Management Centre (April 2013) and Vescio Niranjan of Envirotest (26 April 2013).

38. Stedman, D (2013), 'A New Way Has Been Found to Make Truck Emissions Testing More Accurate and Less Costly', *Scientific American*, 23 May, http://blogs.scientificamerican.com/guest-blog/2013/05/23/a-new-way-has-been-found-to-make-truck-emissions-testing-more-accurate-and-less-costly/ , accessed 25 May 2013.

39. Envirotest Canada (2013), G*reater Vancouver Regional District, Remote Sensing Device Trail for Monitoring Heavy-duty Vehicle Emissions*, February, http://www.trucknews.com/news/b-c-study-uses-remote-sensing-to-measure-truck-emissions/1002225000/ , accessed May 5, 2013; Menzies, J (2013), 'B.C. Study Uses Remote Sensing to Measure Truck Emissions', *Truck News*, 15 April, http://www.trucknews.com/news/b-c-study-uses-remote-sensing-to-measure-truck-emissions/1002225000/ , accessed 5 May 2013.

40. See note 5.

41. More information is available at the website of the Bureau of Automotive Repair's Consumer Assistance Program: http://www.bar.ca.gov/80_BARResources/01_CAP&GoldShield/cap_program.html , accessed 5 May 2013.

42. See TD (2013), 'Vehicle Examination', http://www.td.gov.hk/en/public_services/vehicle_examination/vehicle_examination/ , accessed 18 May 2013.

43. The Lambda test is used to check the air/fuel ratio; the test result can show whether the catalytic converter is functioning properly, or if there are leaks in the exhaust pipe.

44. Hong Kong Government, *Road Traffic (Construction and Maintenance of Vehicles) Regulations of Hong Kong, Cap 374A* – Section 9; European Commission (2009), Directives 2009/40/EC of the European Parliament and of the Council of 6 May 2009 on roadworthiness tests for motor vehicles and their trailers; European Commission (2010), *Commission Directive 2010/48/EU of 5 July 2010 adapting to technical progress Directive 2009/40/EC of the European Parliament and of the Council on roadworthiness tests for motor vehicles and their trailers*.

45. TD, *Annual Transport Digest*, back issues from 2008 to 2012, derived from two tables: 'Vehicle Inspections at Government Vehicle Examination Centres', and 'Private Car Inspection Returns', http://www.td.gov.hk/en/publications_and_press_releases/publications/free_publications/annual_transport_digest/index.html, accessed 30 May 2013.

46. The same annual inspection requirement applies to second-hand vehicles.

47. More information about the EPD's Smoky Vehicle Control Programme can be found at http://www.epd.gov.hk/epd/english/how_help/report_pollution/spotter_training.html, accessed 30 May 2013.

48. Communications with EPD, 10 April 2013.

49. Ibid.

50. Communications with EPD (10 May 2013).

51. EPD (2011), *A Proposal to Strengthen the Control of Emissions of Petrol and Liquefied Petroleum Gas Vehicles for discussion at the Legislative Council Panel on Environmental Affairs*, 28 November; Yam, Y S (2012), *Emission Control of In-Use Petrol and LPG Vehicles in Hong Kong using Remote Sensing and Transient Emission Testing*,presentation at the Motor Vehicle Emissions Control (MoVE) Workshop 2012, December.

52. See note 51, Yam (2012), op. cit.

53. Communications with EPD.

54. See note 51, Yam (2012), op. cit.

55. While the EPD has commissioned research on remote sensing technologies for tracking light vehicle emissions for many years, the technology has not been deployed in any enforcement effort.

56. See note 51, Yam (2012), op. cit.

57. Communications with TD (June 2013).

58. Only first inspections are counted. TD (2012), *Annual Transport Digest 2012*. http://www.td.gov.hk/mini_site/atd/2012/index.html , accessed 25 April 2013.

59. See note 20, McCormick, R et al. (2003), op. cit.

60. ESMAP (2009), *Developing Integrated Emissions Strategies for Existing Land Transport* (DIESEL), Joint UNDP/World Bank Energy Sector Management Assistance Program.

61. IVE (undated), *Groundbreaking Emissions Centre Set up at IVE*, https://edit.vtc.edu.hk/IVE/html/download/article/Groundbreaking%20Emissions%20Center%20set%20up%20at%20IVE.pdf , accessed 20 May 2013.

62. Communications with EPD (20 May 2013). According to the EPD, an average Hong Kong taxi was driven more than 140,000 km a year in 2011, compared to more than 84,000 km for an average light bus and less than 10,000 km for a private car.

63. See http://www.aircare.ca/, accessed 10 May 2013.

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