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Strengthening Vehicle (including motorcycles) Emission Standards and Inspection and Maintenance (I/M)-Benefits and Opportunities for Asian countries Towards SDGs

(Background Paper for EST Policy Dialogue-1)

Final Draft

This background paper has been prepared by Robert Earley, President, Sino-Canadian Commodities Consulting Co. Ltd., for the 12th Regional EST Forum in Asia. The views expressed herein are those of the author only and do not necessarily reflect the views of the United Nations.

Strengthening Vehicle (including motorcycles) Emission Standards and Inspection and Maintenance (I/M)-Benefits and Opportunities for Asian Countries Towards SDGs

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Abbreviations and Acronyms

CO_2	Carbon Dioxide
HC	Hydrocarbon
I/M	Inspection and Maintenance
MIIT	Ministry of Industry and Information Technology of the People's Republic of China
NOx	Oxides of nitrogen
OBD	On-Board Diagnostics
PM	Particulate matter
$PM_{2.5}$	Fine particulate matter
SDGs	Sustainable Development Goals
VOC	Volatile organic compound

Executive Summary

The transportation sector is an important source of air pollution and greenhouse gas emissions in Asian cities, along major inter-urban transport corridors, and at major transportation hubs. While on average, transportation is responsible for between 2-10% of air pollution exposure (on a population-weighted basis) in Asia, some cities with higher focus on transportation as an industry experience higher exposure. As part of the objective of meeting the Sustainable Development Goals identified in the 2030 Agenda for Sustainable Development, emission standards for new vehicles and fuels, as well as inspection and maintenance systems for in-use vehicles are key for improving the performance of society in terms of energy efficiency (Target 3.6), reduction of air pollution (Target 3.9), and the mitigation of climate change (Target 13.2).

Countries in Asia and the Pacific face huge challenges in designing and implementing emission and fuel standards, and their linked inspection and maintenance (I/M) systems that help to address the SDGs noted above. First, especially for developing countries in Asia and the Pacific, higher costs associated with stronger emission control systems in vehicles present create a conflict between the desire to reduce emissions from vehicles with economic development. Second, clean fuel (particularly low-sulfur fuel) to power vehicles of higher emission standards is not available in all countries, and requires heavy investment by fuel refiners (in some cases state-owned companies) to achieve. Without clean fuel, the emission control systems of clean vehicles can be irreparably damaged, at great expense to the vehicle owner. Finally, I/M systems themselves require a high level of technical competence at the central and local government levels, a firm commitment to protection of the environment through proper implementation of vehicle inspection and reduction of corruption at the local level, and investment in equipment that can properly inspect and certify vehicles across entire countries. Finding a balance between public and private investment, and undertaking consistent, fair and reasonable enforcement of emission rules, as well as ensuring that I/M programs are sustainably funded for the long-term implementation of emission standards require deep commitment and iterative review and policy making to ensure effectiveness. Unfortunately, public pressure to avoid the testing and recertification of some key vehicle segments, such as two- and three-wheeled vehicles in some countries is seen as a key impediment to cleaning up transport emissions.

Given the existence of well-designed standards and I/M programs in countries in Asia and the Pacific, there are huge opportunities for achievement of SDGs, particularly in the areas of road safety, air pollution reduction, and energy efficiency. First, periodic inspection of vehicles gives vehicle owners and opportunity to think carefully about the state of their vehicle to ensure that it is in good operational condition. Checking the On-Board Diagnostic light to ensure no maintenance is needed, ensuring that engine fluids and lubricants are at good levels and conditions, ensuring that lights and mirrors are functional, ensuring that the steering system is operating properly, and ensuring that tires are in good operational condition are all issues a driver may want to check before attempting to re-certify their vehicles in a properly operating I/M framework. Regular maintenance of vehicles may improve fuel economy by as much as 20% in some vehicles, meaning potentially huge savings for vehicle users, and important improvements for energy security at the national level. Additionally, dysfunctional emission control systems on vehicles can emit tens or even hundreds of times more pollution than properly functioning cars – pollution that has important social and economic impacts on countries. In California, it is estimated that 50% of smog in the state is generated by 10-15% of vehicles that are improperly maintained and thus are considered “gross emitters”.

I/M policies and processes are now considered to be "mature" in many developed countries, and in an increasing number of developing countries. The best I/M programs are centralized, either directly operated by government or by government-certified testing organizations. Testing should be done by an organization separate from maintenance companies, and testing should be linked directly to renewal of a vehicle's registration, meaning that vehicles that do not pass an inspection should be placed into a mandatory maintenance cycle of some sort before re-issuing vehicle registration. From a technical perspective, On-Board Diagnostic (OBD) systems should be examined as part of any automotive certification review, and the information should be collected and recorded in a vehicle's record to compare against the finding of the physical check by the technician. The results of a vehicle's testing should be placed into a central electronic database so that if a vehicle is ever found to be particularly polluting, it can be traced back to the testing facility to see if there are other problems that need to be addressed locally. Remote roadside testing is an increasingly important tool for ensuring compliance with emissions and maintenance standards, and P.R. China became the first country to develop a national protocol for remote sensing emission testing on roadways.

While emission standards and testing techniques for conventional vehicles improve, electrification of transport offers a major technological change that eliminates most emissions from vehicles completely, particularly at the local level. Countries in Asia and the Pacific are experimenting with electrification of all types of vehicles, with particular leadership undertaken by P.R. China, which has goals to replace significant fraction of its car, city bus, urban maintenance and even local delivery truck fleets with electric vehicles in the mid-term with nearly complete replacement in the longer-term future. Other countries across Asia and the Pacific are undertaking pilots and building up their own EV industries. The main low-hanging fruit for electrification is electric two- and three-wheelers. Although they have been met with resistance in many countries, P.R. China now has annual production of over 20 million and over 300 million electric two- and three-wheelers on the road. These vehicles are relatively low cost to purchase, and much less expensive to operate than conventional vehicles – and have been found to have lower emissions on a lifecycle basis than any other powered vehicles on the road. The price of new lithium battery technology is decreasing thus reducing the chance that lead-acid batteries will be improperly discarded and thus polluting roadsides and waterways. Tested over more than a decade across a broad range of climates, electric two- and three-wheelers are a major opportunity to reduce GHG, air and noise pollution in some cities in Asia and the Pacific where two- and three-wheelers make up as much as 70% of the automotive population.

With the evolution of automotive technology, emission standards and I/M systems must also evolve. Now that most new vehicles have OBD systems as part of compliance with Euro and other international emissions standards, their data should be used to ensure that vehicles are properly maintained at all times. Remote sensing of pollutants can link to electronic databases to the owners of vehicles to notify them of the need to have their vehicle inspected in case of high pollutant emissions. But electrification could be the largest disruptor to this system. While hybrid vehicles may still require emission testing, fully electric vehicles have no need for such inspections and may only require roadworthiness testing in the future. Governments will need to carefully monitor the growth of EV fleets in their jurisdictions in order to properly prioritize investment in I/M facilities. As part of their fleet characterization studies, governments may want to identify the major polluting vehicles such as diesel buses or two- and three-wheelers and divert funding to electrifying those transport modes instead of massively scaling up I/M systems. Electric two-wheelers are a proven technology for urban transport with potentially to

massively reduce emissions from the transport sector in urban areas. Public buses and urban delivery vehicles are also fleets that tend to experience high emissions but can be more easily addressed by governments because they are typically highly regulated by governments.

The conclusion is that a clean transportation system is well within reach, even if it will take decades to achieve. From the perspective of vehicles, clean transportation will see a shift towards electrification over time, but as that happens, a balance needs to be made in order to ensure that existing vehicles are not emitting toxic and climate-forcing emissions. I/M systems are essential to ensuring that vehicles perform to their potential, to reducing emissions and to saving fuel and expense for drivers. At the same time, even without I/M systems, drivers can be encouraged to perform basic automotive maintenance in order to ensure energy efficiency and safety of their vehicles.

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1.0 Background

The transportation sector is an important source of air pollution and greenhouse gas emissions in Asian cities, along major inter-urban transport corridors and near major transportation hubs such as air- and sea-ports. The explosion of personal vehicles such as cars and petrol-fueled motorcycles, tricycles and other small personal vehicles across the region have perceived and real impacts on health and quality of life in cities that give policy makers increasing pressure as residents become more aware of the negative implications of breathing air pollution and the changing climate.

According to the State of Global Air 2019 report (Health Effects Institute 2019), air pollution was the fifth-highest ranking risk factor by total number of deaths for all ages and sexes in 2017 and contributed to nearly five million deaths globally. The report states that in Asia and the Pacific, annual $PM_{2.5}$ exposures were highest in the South Asian countries of Nepal, India, Bangladesh and Pakistan, while the East and Southeast Asian countries such as People's Republic of China, and Indonesia experienced somewhat lower exposure on average, although still much higher than WHO Air Quality Guidelines. As a risk factor associated with 4.9 million lives and 147 million years of healthy life lost, air pollution is a significant risk to quality of life, economic development, agriculture and food security, social security and other key areas of human and ecological health. A World Bank report (2016) indicated that the welfare cost of total air pollution in East Asia and the Pacific was highest in the world at 7.5%, and ambient $PM_{2.5}$ pollution at 4.5%, while South Asia followed close behind at 7.4% of GDP for total air pollution, and 3.1% for ambient $PM_{2.5}$.

The role of transportation in air pollution and climate change is important. Anenberg, et. al (2019) indicated that transportation-related emissions of $PM_{2.5}$ and ozone were responsible for 12% of combined $PM_{2.5}$ and ozone deaths in the Association of South East Asian (ASEAN) trading bloc, 11% in China, 9% in the South Asian Association for Regional Cooperation (SAARC) trading bloc, 16% in South Korea and 19% in Japan. Diesel- and heavy distillate fuel-related emissions from international shipping, off-road mobile, and on-road diesel vehicle sources are responsible for 70-80% of those deaths, indicating the importance of managing diesel vehicles in the fight for cleaner air and reduction of health impacts from the transport sector.

New studies have specifically identified the role of transportation in $PM_{2.5}$ emission in countries across South and East Asia (Figure 1). In fact, transportation ranges from 1% to 10% of $PM_{2.5}$ emissions with the highest proportions observed in India, Nepal, Bhutan and Bangladesh, while in countries with more industrial pollution sources and exposure to natural fires, transportation makes a lower contribution to overall exposure to $PM_{2.5}$ exposure overall.

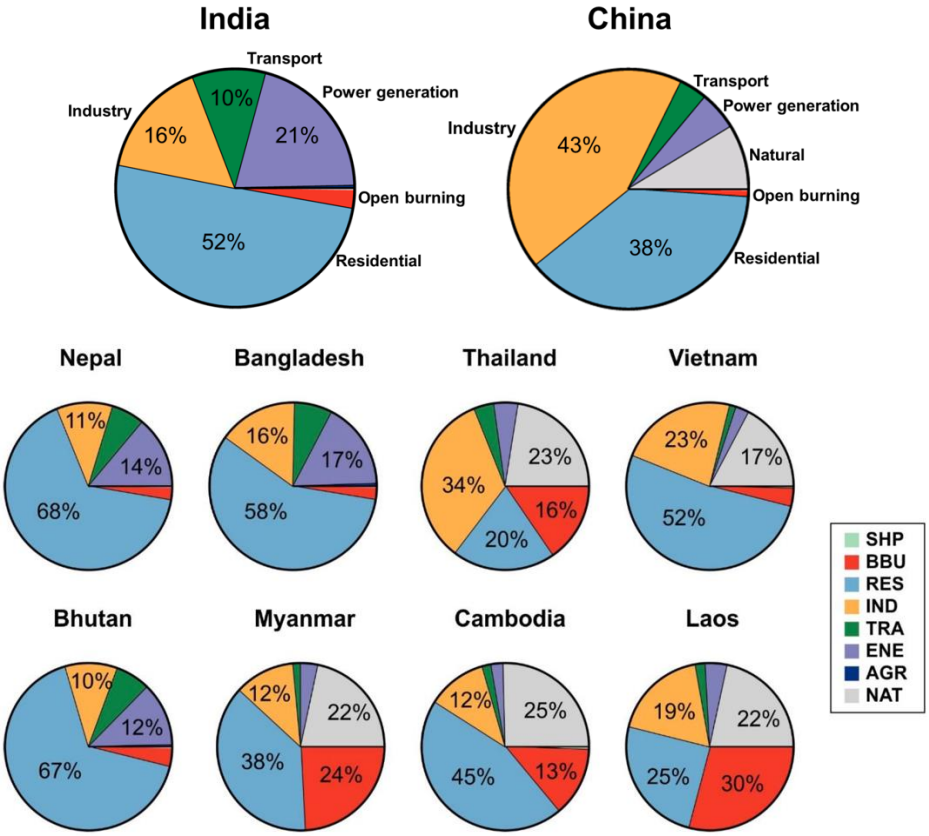


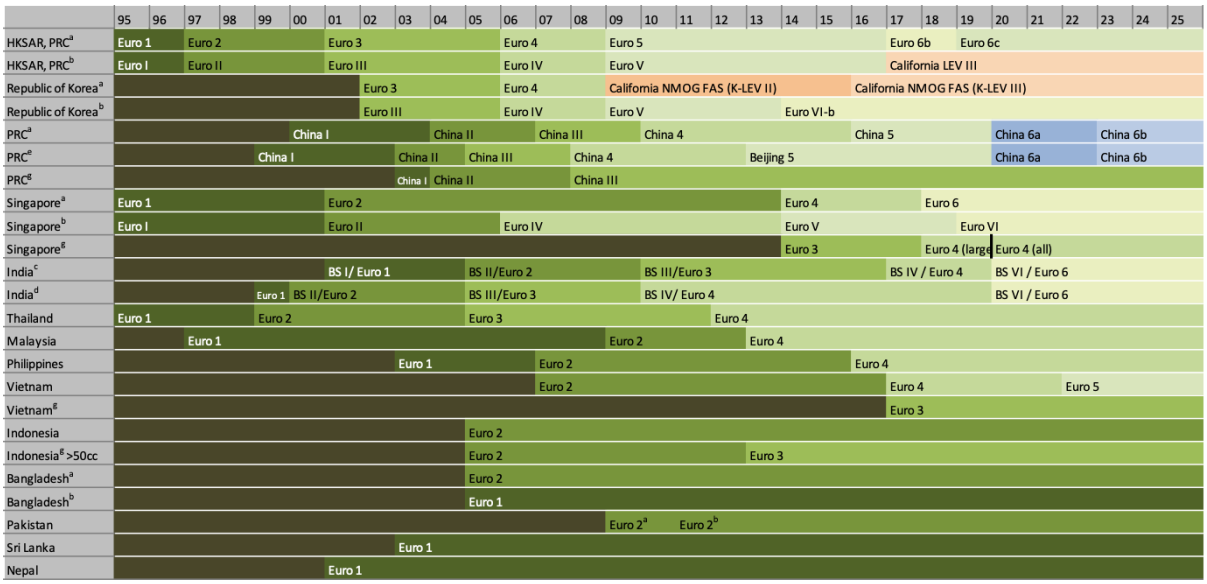
Figure 1 Relative contributions of different anthropogenic emission sectors to population-weighted annual mean PM2.5 concentration. SHP = Shipping, BBU = Open Burning, RES = Residential indoor air pollution, IND = Industrial, TRA = Land transportation, ENE = Energy generation, AGR = Agriculture (especially burning), NAT = Natural sources (especially fires) Source: Reddington et. al (2019). Replicated under licence CC BY 4.0.

Although the data in Figure 1 suggest that land transportation is a relatively small contributor to $PM_{2.5}$ emissions in Asian countries, this is only because other emissions sources in these countries are huge – reducing emissions from the transportation sector still represents a significant opportunity to reduce loss of life across the region, particularly in urban areas, and is an emission source for which there is a clear pathway and responsibility.

While transportation may not be the largest source of air pollutant emission in countries in Asia and the Pacific, its contribution to GHG emissions is more substantial. According to data from the International Energy Agency (IEA 2014), transportation accounts for between 3.5% in

Democratic People's Republic of Korea (DPRK) to 63% in Cambodia, with an average of 10.8% in East Asia and the Pacific, and 13.0% in South Asia (as defined by the IEA).

One important means of controlling the emissions from vehicles is to ensure that new vehicles are built and sold according to standards that limit fuel consumption (and thus CO_2 emission), as well as pollutant emission, including total and fine particulate matter (PM and $PM_{2.5}$); carbon monoxide (CO), ozone, oxides of nitrogen (NOx); oxides of sulfur (SOx); volatile organic compounds (VOC), hydrocarbon (HC); and, other air pollutants. Many countries in Asia and the Pacific have plans to increase the stringency of automotive emission standards over time through the implementation of Euro standard systems and the associated improvements in fuel quality standards (Figure 2, Figure 3).



Notes:
a – gasoline
b – diesel
c – entire country
d – Delhi, Mumbai, Kolkata, Chennai, Hyderabad, Bangalore, Lucknow, Kanpur, Agra, Surat, Ahmedabad, Pune and Sholapur
e – Beijing [China I (1999); China II (2003); China III (2005); China 4 (2008); Beijing 5 (2013)], Shanghai [China I (1999); China II (2003); China III (2007); China 4 (2009); China 5 (2014)]; Guangzhou [China I (2000); China II (2005); China III (2006); China 4 (2010); China 5 (2015); and, 11 Eastern Provinces [China 5 (2016)]
f – Equivalent to Euro 4 emissions standards
g - motorcycles
China has very few diesel passenger vehicles, therefore emission standards are not detailed here

Figure 2 Light Duty and Motorcycle (where data is available) Type Approval Emission Standards for Selected Asian Countries (Source: Various national sources, based on Clean Air Asia 2015)

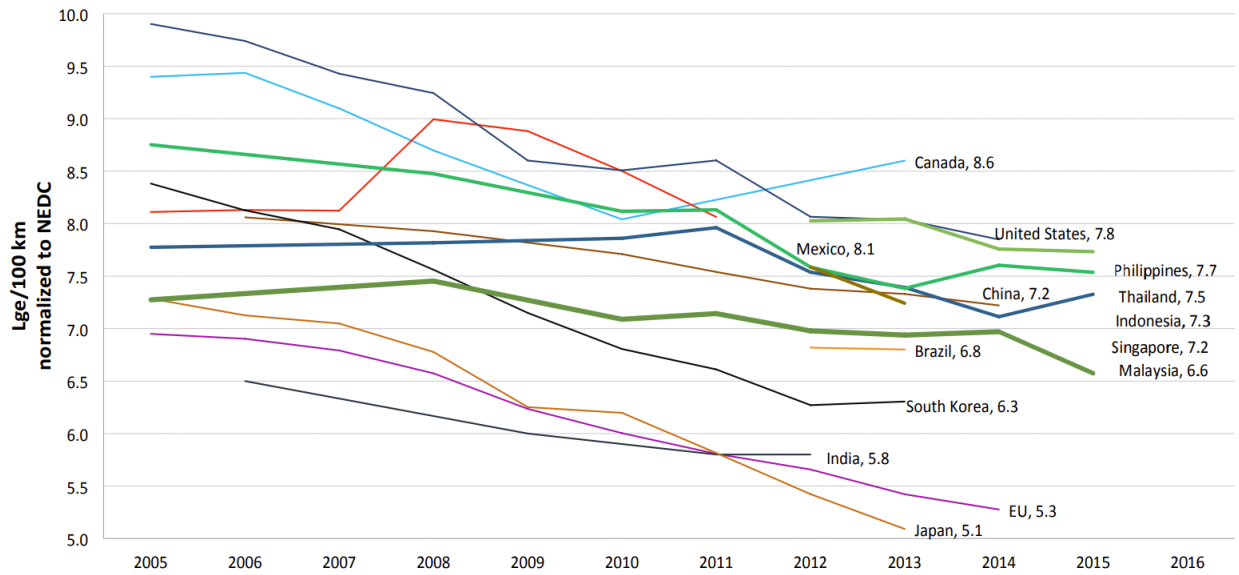


Figure 3 - Fuel Economy Baselines Study conducted by the Global Fuel Economy Initiative in ASEAN and the World (Source: ASEAN Secretariat 2019)

While emission standards for new vehicles are an important strategy, the fact is that vehicles face wear and tear over time and can eventually become out of tune or damaged. Sometimes vehicles are even illegally modified by their owners to increase driving performance while decreasing environmental emission reduction performance. When vehicles are old, out of tune or damaged, they no longer perform according to the standards by which they were manufactured, and emissions can increase dramatically. These vehicles are known as "gross emitters." In 2004, gross emitters were estimated to make up 10-15% of the Californian automotive fleet, based on the definition that they were responsible for more than 50% of a smog-generating pollutant such as ozone or NOx. Based on this definition, it is clear to see that a small number of poorly maintained vehicles can have a major impact on air quality in a region.

In principle, newer vehicles should be cleaner and more efficient than older vehicles, given that emission standards tend to improve over time. But even as new and cleaner vehicles come onto the road, older, more polluting vehicles remain on the road. Meanwhile, a lack of proper inspection systems and the use of poor-quality fuel (especially diesel), all lead to a high and increasing proportion of primary and secondary air pollution and GHG emission from the transport sector. That some automotive companies have been found to purposely use defeat devices in their cars to cheat during testing has dramatically confused the situation (EPA 2015), rendering laboratory testing unreliable for some vehicles, especially when governments do not implement strict supervision and consistently apply high technical capacity to detect cheating.

The key to ensuring that vehicles remain within their optimal and desired emission and fuel consumption range is to regularly maintain those vehicles. Vehicles that are not regularly maintained can quickly become gross emitting vehicles, spewing smoke and hazardous chemicals into the atmosphere and directly affecting the health and well-being of urban residents, especially children, the elderly, and the sick. Poorly maintained vehicles also experience significantly higher fuel consumption (Macgregor 2018). Yet vehicle maintenance is an economic burden that many vehicle owners wish to avoid. If a vehicle can still perform its primary task of transporting goods or people, owners and drivers are often hesitant to take on the often high costs of vehicle repair, with the argument that their own individual vehicle is not likely to cause a major pollution crisis for a whole city. Drivers are also often conservative in estimating the potential fuel and money savings related to vehicle maintenance. In such unregulated situations, the tragedy of the commons can be observed – and emission control systems and the condition of vehicles overall can fall into disrepair.

The main policy solution for this market imbalance is the automotive inspection and maintenance (I/M) system that requires vehicles to undergo regular in-use emissions testing in order to be certified for another period of on-road use. I/M programs, often combined with road worthiness inspections are designed to identify high-emitting vehicles and mitigate their impacts on air quality and climate, and have been found to be highly cost effective in countries such as the United States (Li 2017). I/M programs, in addition to the familiar regular periodic testing centres where a technician will use equipment to examine a vehicle's exhaust stream at a fixed facility, can also include on-road identification of gross emitters, where enforcement agencies can either utilize portable exhaust analysis equipment and request that vehicles pull to the side of the road for testing, or even place remote sensing equipment and cameras to detect offenders as they drive by. Modern automotive technology is also evolving to ensure that the on-board computers of cars accurately report and report maintenance issues through On-Board Diagnostic (OBD) reporting so that testing centres do not only have to rely on emissions to determine if a vehicle is roadworthy or not. These different testing modes will be examined in the following chapters.

However, automotive technology is advancing in a different direction as well – towards electrification. Although electric vehicles still experience emissions such as particular matter related to tire wear, they do not experience the mass emissions of on-board fuel combustion

meaning that I/M becomes less relevant for the protection of society against air pollution. With increasing electrification, especially of key commercial diesel emitters like public buses and urban maintenance fleets, the role of I/M will likely change over time, with less emphasis on emissions and more emphasis on energy efficiency and road worthiness. As part of the consideration in electrification policy, policy makers will be forced to balance the costs of maintaining today's fuel-based transport fleets against an increasingly electric fleet in the future.

2.0 Major challenges in improving fuel quality and emission standards and inspection and maintenance of vehicles in Asia

Despite the clear health benefits of improving fuel quality, emission standards and I/M of vehicles in Asia and the Pacific, many countries across the region face significant challenges in creating and implementing policies to drive down final tailpipe emissions. There is an entire value chain of challenges that results in higher emissions than desired coming from vehicles, and the challenges have been a focus of transportation and environment for decades:

New Vehicle Emission standards

Emission standards are the technical basis for vehicles to reduce the emissions generated from use and combustion of fuels for operating the vehicle. Emission standards can address the emissions coming from the tailpipe of the vehicle as well as non-combustion emissions such as evaporative emissions that come from the fuel tank, fuel lines and drive train both while the vehicle is being refueled, while it is operating, and while it is at rest.

Today's emission standards are defined for a vehicle at the moment it is permitted to be sold to market. That means that emission standards apply to new vehicles. Typically, not every new vehicle is tested to ensure that it will meet standards. Rather, a type-approval process is undertaken, where the manufacturer of a vehicle will supply a sample vehicle, have the sample vehicle tested to ensure conformance with the emission standard (such as Euro 4, 5, 6 (petrol) and Euro IV, V, VI (diesel) etc. under the European system or LEV I, II, III, etc. under the U.S. system), and the results are submitted to government to register that the model of vehicle conforms with the standard. In today's most advanced standards, vehicles must conform not only to a dynamometer test, but also to a test under real-world driving conditions while using a Portable Emissions Measurement System (PEMS). Upon acceptance of test results by the regulator, the production vehicles can be sold on the market, usually without additional pre-market testing.

Advanced emission standards also have increasingly stringent requirements for On-Board Diagnostics (OBD) systems that continuously monitor the emission control system on a vehicle to ensure that the system is operating properly. The OBD system, part of the vehicle's engine computer, makes use of various sensors and other data input to alert the driver when the vehicle

requires maintenance, and can be used to tell a vehicle mechanic more detailed information about the specific problem with the vehicle. OBD systems are now part of Euro and other international automotive standards, and part of the requirements are that they are readable by vehicle inspectors. OBD systems can also be accessed by vehicle owners using specialized equipment to record information about their vehicles such as fuel consumption, engine status and other data that can help improve fuel efficiency, safe driving and other characteristics (Amarasinghe et al. 2015).

Aside from setting the final emission limits and test methodologies, emission standards to not typically prescribe the technologies for auto manufacturers to achieve conformance with the standards. Unfortunately, most of the technologies used to control emissions of fuel-powered engines are highly sensitive to the quality of fuel that is used, and therefore emission standards are highly dependent on fuel quality standards.

Motorcycles face special challenges in the area of emission standards primarily because on one hand, most people view motorcycles as smaller than cars and therefore cleaner than cars and do not understand the urgent demand for emission standards and inspections, and on the other hand, in many cases are much lower cost than cars or other light-duty vehicles, and therefore users may be resistant to paying to repair emission control systems on motorbikes. However, motorbikes without stringent emission control systems are serious polluters. In 2011, it was estimated that although motorcycles in California were responsible for only 1% of total distance travelled in the state, they were responsible for 13% of hydrocarbon emissions (Carpenter 2011). For the 2011 model year of motorcycles, although they consumed 28% less fuel than a comparable car, they emitted 416% more hydrocarbons, 3220% more NOx and 8065% more carbon monoxide. Clearly, standards and inspection and maintenance are important for these vehicles. Although motorcycles in California are typically larger than those found in Asian cities, the challenge remains similar as the population of motorcycles in Asian cities is dramatically larger.

Fuel Quality Standards

Because the technologies required for vehicles to achieve conformance with emission standards require increasingly clean fuel, fuel quality standards are often linked to progress towards more stringent automotive emission control standards. For example, in petrol-fueled vehicles, one of the main technologies for controlling emissions from the engine is a catalytic

converter which converts toxic engine emissions into benign emissions. However, the catalytic converter is severely inhibited by sulfur in fuel, and has brought about the requirement that now petrol in Europe, United States, Canada and other countries with stringent emission standards have sulfur levels of approximately 10 parts per million (ppm)[1]. Similarly, diesel emission control systems that use catalysts to reduce particulate matter, NOx and other emissions in diesel exhaust require the lowest amount of sulfur content in diesel possible in order to ensure the catalysts are not permanently damaged, thus reducing the ability for emission control systems to reduce the toxic emissions from being emitted to the nearby roadway.

Fuel quality standards depend heavily on the ability of refineries to produce adequate supply for the transportation fleets they serve. Even today, sulfur concentration in fuels ranges from 10 ppm in Japan and P.R. China to 10,000 ppm in Indonesia (Abdoun 2019), severely limiting the ability of countries with high sulfur content from implementing emission standards that require catalytic converters or Diesel Particulate Filters (DPFs). Eliminating sulfur from fuel supply requires significant capital investment by refiners in equipment such as hydrotreatment units that remove sulfur from fuels. These units are not always compatible with existing refineries, meaning that some countries do not have sufficient refining capacity to serve their own markets without the need for significant multi-million dollar upgrades to their refining infrastructure.

Inspection and maintenance programs

While automotive emission standards and fuel quality standards primarily affect the behavior of companies in the production of their products, I/M programs have a much more direct impact on the general population of a country. On one hand, the impact comes because it is the vehicle owners who have to pay for their vehicle to be inspected. On the other hand, vehicle inspection is an area where members of the public need to pay a fee to a government-sponsored entity, leading to potential for popular discontent and suspicion about fees and potential corruption by testing centres. Additionally, publicly-funded testing centres may fall into disrepair without a careful auditing and certification system in place to detect improper certifications.

[1] In Canada, for example, the sulfur content of gasoline is regulated in two different ways: a fuel provider may sell fuel at a constant quality of 14 mg S/kg gasoline until 1 January 2020, then 12 mg/kg after that, *or* a fuel provider's average fuel sulfur content should be 10 mg/kg, with a batch limit that may never exceed 80 mg/kg. There is a temporary sulfur credit trading market for primary producers in place to ensure compliance up to the end of 2019. (Government of Canada 2017)

Clean Air Asia (2016) notes that "Inspection and maintenance programs are inherently difficult to design and implement since they rely heavily on the participation and investment by private citizens or companies to safeguard a public good – clean air," while noting that voluntary systems are not viable because individuals in many situations would not voluntarily pay to ensure their vehicles are in good repair, especially if others are not required to do so. As a result, "consistent, fair and reasonable" enforcement of emission rules is necessary for successful programs to take place.

Perhaps most important in the implementation of emission standards and I/M systems is the commitment of government and government officials to properly develop and provide funding for systems that can provide consistent, long-term and accurate monitoring of automotive performance. When countries focus on economic development, they may face a conflict of priorities in supporting a system that appears to be expensive and burdensome for the population. It is key for government to have a clear picture of the costs of pollution related to gross-emitting vehicles in terms of health and productivity of the population, potential for lost lives due to pollution-related disease, and the economic costs of health care in order to prioritize the development and effective operation of I/M systems.

Box 1 India's "Pollution Under Control (PUC)" Certification Program – A Case Study (based on Raman and Shukla 2018)

Studies conducted in Delhi revealed that in winter, 28% of $PM_{2.5}$ emissions were coming from the transport sector. At the same time, 60% of those emissions were coming from the 20% of vehicles on the road that were poorly-maintained or old (Goel and Malik 2018). An investigation of the PUC certification program was ordered by the Supreme Court to establish why the I/M system was not working.

According to Section 56 of the Motor Vehicles Act (1988), commercial vehicles in India need to be assessed for fitness. Rule 116 of the Central Motor Vehicles Rules (1989) requires that the emissions of vehicles be inspected. Commercial vehicles need to be tested annually and obtain a certificate of fitness, while in Delhi they need to be inspected every three months, and every six months in some other states. However, private vehicles do not require mandatory fitness and safety checks until they are 15 years old. The first phase of the I/M program (1991-2004) saw vehicles undergo a very simple test for carbon monoxide for petrol/CNG/LPG vehicles at a low idling speed, and smoke opacity from diesel vehicles during free acceleration. Only in 2004 was a hydrocarbon (HC) test added to petrol/CNG/LPG vehicles, as well as lamda value to test the effectiveness of the catalytic converter. Most testing was done in small shops at refuelling stations using a gas analyser and a smoke meter across most of the country. During an inspection ordered by the Supreme Court in 2017, it was discovered that although testing centres are linked to a central database in Delhi, data collection faces serious issues, and data is poorly collated and analysed at the central database. Furthermore, key data such as year of manufacture, vehicle type and fuel type were not collected. During the 2017 investigation, it was also found that a high number of fraudulent certifications, fake testing software, and inappropriate testing methodologies were found. Nearly 20% of tests indicated zero emissions for CO and HC, a virtually impossible outcome, indicating that either no test was actually done, or was done improperly.

The 2017 investigation also found that the centralized database was also being used ineffectively for developing observations about the I/M system and for understanding trends in automotive performance that might inform policy making. The study found that it is not clear how many vehicles are actually tested each year, although a preliminary analysis estimated that only 23% of 5.91 million vehicles in Delhi were being tested, and even then, nearly all vehicles were passing. 1.68% of diesel vehicles failed the smoke opacity test, and 4.5% of petrol vehicles failed

the CO and HC tests, reflecting that the limits on emission for in-use vehicles are not stringent enough. At the time of the study, although vehicles whose OBD light was on could not pass the inspection, there was no requirement to test the OBD system itself to ensure proper operation, nor to check the data on the OBD system to make more informed pass or fail decision.

The conclusion of the 2017 Supreme Court study was that despite a comprehensive I/M system being in place, the government's emission testing system had failed to identify gross polluters.

Based on the findings of the study, recommendations were made:

1. Limit the number of inspection centres, and upgrade them with improved supervision and quality control
2. Ensure 100% compliance by linking annual vehicle insurance with certification
3. Automate certification data uploading to ensure manual interference of data entry
4. Ensure payment is made before the emission test
5. Strengthen inspection and licensing of testing centres.

Further research was also requested on the integration of OBD systems into the certification program; making limits for pre-BS-IV (pre- Euro IV/4) vehicles more stringent, and integration of Real World Driving Emissions (RDE) monitoring into BS VI emission standards in 2020 to ensure that type approval testing is not being manipulated by vehicle manufacturers as in the so-called "Dieselgate" scandal.

Each country faces challenges for the implementation of its I/M system. For example, a study undertaken by Clean Air Network Nepal, et al (2013) noted that in Nepal, the "Green Sticker" for tested vehicles is not mandatory for vehicle registration renewal; the I/M program is only valid within Kathmandu; there is no mechanism for monitoring the I/M system independently (i.e. with roadside emissions monitoring); and, there are no provisions for two- or three-wheeled vehicles – a major proportion of vehicles in Nepal.

Meanwhile, even countries with advanced I/M systems such as P.R. China where policy for cleaner air through stringent emission standards and comprehensive automotive testing protocols, there is frequent online advice about how to pass tests available. There is even information available noting that services may be available outside testing centres that a payment could be made to an agent outside the testing centre to ensure that a car's emission test could be passed (e.g. Luo 2018).

Motorcycles and three-wheelers face special challenges for in-use testing as well as for new vehicle emission standards. ICCT (Posada, et al, 2011) noted that I/M programs lack oversight at test centres, lack professionalism and lack public credibility, meaning that better training is necessary for technicians and managers, and that public education is also necessary to raise the profile on the importance of I/M for improving air quality. Additionally, OBD systems that help identify vehicles with maintenance issues are typically only found in larger two- and three-wheelers certified to the Euro 4 equivalent standard. Unfortunately, there are few motorcycle-majority countries that currently insist on Euro 4 equivalent standards for new motorbikes to date (see Figure 2). Public awareness is key to ensuring that not only are I/M systems accepted by the public for motorbikes and three-wheelers, but that members of the public sell and purchase vehicles with more stringent emission control systems whenever possible, or even electric vehicles where available.

3.0 Opportunities and solutions arising from improved emission standards, I/M and enforcement measures

The opportunities and solutions arising from improved emission standards, I/M and enforcement measures are clear. Cleaner vehicles that are better maintained will result in less pollution in cities. Figure 4 clearly indicates that as vehicle population grows, those vehicles that have less stringent emission controls – particularly two- and three-wheeled vehicles, will have the most dramatic impact on urban pollution.

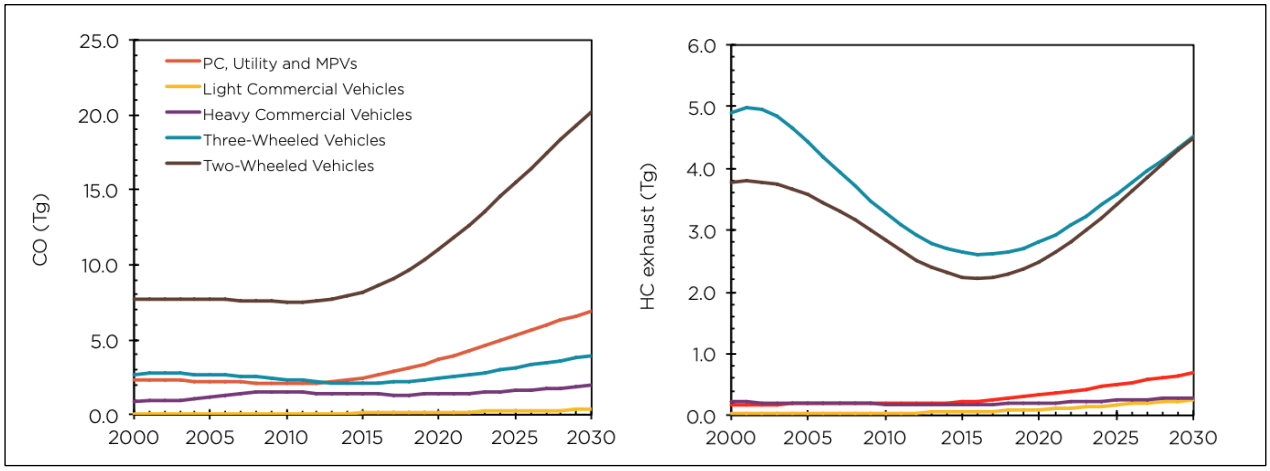


Figure 4 CO and HC emission share by transportation mode for India. Source: Posada, et al, 2011

While various models of I/M systems have been advocated and attempted over time, evidence from experience in developed and developing countries around the world suggests that with the well-planned and scheduled tightening of emissions standards over time, centralized I/M systems, where the entities that provide inspection are separate from and unrelated to the entities that perform maintenance have the best results in terms of system efficiency and fraud reduction (Kolke 2005).

Comprehensive systems of vehicle and fuel standards, combined with inspection and maintenance of vehicles on a regular basis are key to ensuring that vehicles are not only performing according to their design specifications, but also save fuel and produce minimal air polluting and climate-forcing emissions. In addition to the major automotive producing markets such as the US & Canada and Europe, some countries in Asia and the Pacific have made great strides in strengthening standards and enforcing I/M policies, including the People's Republic of China, Japan, Singapore and India. Meanwhile countries such as Thailand,

Viet Nam and Pakistan are realizing the importance of driving emission standard enforcement for building up leading automotive industries, as well as for taking control over air pollution, even as they face challenges.

This section will introduce the standards of cars, trucks, motorcycles and three-wheelers in best-case countries in Asia, including some of the positive outcomes of those emissions standards. I/M systems in P.R. China, Singapore and Japan will be featured, and in particular, remote roadside testing programs practiced in P.R. China will be introduced to demonstrate how they complement the vehicle inspection system.

Before noting the potential opportunities for I/M in Asia and the Pacific, it is important to outline the main structure of a good I/M program:

- A suitable test procedure, supplemented by inspection of Emission Control Systems
- Effective enforcement of Vehicle Compliance
- Adequate attentions to repair procedures
- Routine quality control
- Enforcement of proper enforcing guidelines
- Periodic evaluation, reviews and solution enforcements
- Minimization of repair costs and access to subsidies and exemptions on repair parts

Passenger Cars

Passenger cars, being the most populous enclosed vehicles in many countries, are of key concern to governments not only for ensuring that vehicles are low emitting, but also that they

<u>P.R. China</u>

P.R. China takes a comprehensive Vehicle-Fuel-Traffic approach to reducing the emissions of the transport system. In addition to developing and beginning to roll-out some of the world's most stringent emission standards for new cars and trucks (China 6 and VI) including standardized OBD, vehicles also need to be inspected on a regular basis. Furthermore, China has recently released a national protocol for fixed-location remote sensing of high-emitting

vehicles that helps to detect those high-emitters that have either been missed by regular testing, or have becoming non-conforming between tests. In addition to a regular I/M system in place, China operates a regular scrappage program called the "Yellow Label Vehicle" program with a rolling standard that forces undesirable vehicle off the road. These vehicles, upon their inspection receive a yellow label instead of a green label, notifying them that they will have to be permanently taken off the road in a prescribed period of time. These vehicles may pass current emission tests, but the government has decided that they are too old to be suitable for use any longer due to obsolete emission control systems.

Figure 5 A yellow vehicle inspection label indicating that the vehicle is scheduled to be removed from the road at a prescribed time. Source (China Daily)

Inspection of in-use vehicles in P.R. China is enabled by *The Regulation on the Implementation of the Law of the People's Republic of China on Road Traffic Safety*, adopted 28 April, 2004, stating that motor vehicles must pass certain regular inspections. In addition to the national regulations, local governments also have the authority to introduce specific inspection requirements based on their local conditions. Nationally, four government departments are responsible for inspection:

1. National Development and Reform Commission is in charge of testing new vehicles in terms of emissions before they are put into use. The Ministry of Industry and Information Technology is in charge of fuel economy testing for type approval.

2. Ministry of Public Security is in charge of safety testing of in-use commercial and non-commercial vehicles, at the following frequencies after a vehicle is registered:
    a. Commercial passenger vehicles: inspected every year for the first 5 years, then every 6 months thereafter;
    b. Trucks and large or medium-sized non-commercial passenger vehicles: inspected once every year for the first 10 years, then every 6 months thereafter;
    c. Small or mini non-commercial passenger vehicles: inspected every 2 years for the first 6 years, then once every year thereafter up to 15 years. After 15 years it shall be inspected every 6 months.
    d. Motorcycles should be inspected once every 2 years during the first 4 years, and once per year thereafter.
    e. Tractors and other motor vehicles should be inspected annually.
3. The Ministry of Ecology and Environment is responsible for in-use emissions testing. All vehicles should be tested once per year.
4. The Ministry of Transport is in charge of comprehensive function testing, conducted at an automotive multi-functional test station.

4.0 Status of electrification of vehicles in Asia, and the major opportunities and benefits in the areas of emission and I/M

While I/M systems are key to reducing emissions from conventionally-powered vehicles, it is now a worldwide trend that personal and commercial on-road transportation are moving towards electrification, which brings different considerations to the issue of inspection, maintenance and emissions. Countries in Asia and the Pacific have also realized that there are great environmental and social benefits to electrification of vehicles and have begun to undertake pilot projects, encourage industrial development, and roll out policies to bring about a shift towards electric motorbikes and scooters, electric min-cars and full-sized cars, electric three-wheeled passenger vehicles and trucks, electric jeepneys, electric buses and electric freight vehicles.

Electrification comes in various forms according to the technologies offered by different companies and the demands of various markets in the region. Electrification was led initially by Japanese companies such as Toyota and Nissan, which introduced the world-famous

hybrid Prius as well as the well-known battery electric Leaf cars that have left a deep impression on car users around the world. Early on, these two cars left users with an option to either use a hybrid electric vehicle that can use petrol to charge its on-board battery and use electric power when it is most efficient, or to use pure battery electric drivetrains charged from grid power. Later, a variety of plug-in hybrid vehicle configurations have given drivers the choice to primarily charge their car batteries with grid power, while leaving open the option to use a fuel-powered motor for either main drive power or for charging the on-board battery. Similarly, many different options exist for public urban transit buses as well as long-distance buses.

Electric Two- and Three-Wheelers

News reports often focus on the development of electric four-wheeled vehicles as the EV revolution – however, some would say that the EV revolution is already well underway in Asia. Electric two-wheelers have also been revolutionized by electric power. In P.R. China, the epicenter of electric two-wheeler scale-up, sales of e-bikes rose from 40,000 per year in 1998 to 10 million per year in 2005 (Weinert, et. al 2006), and now stands at over 22 million per year (Moskvtich 2019). There were over 480 original equipment manufacturers in P.R. China in 2005 (Weiner, et. al 2006). Today, the population of electric two-wheelers in P.R. China has expanded to over 250 million in daily use, and the population of electric three-wheelers has expanded up to 50 million (IEA 2019, Moskvitch 2019).

Although sales of electric two- and three-wheelers have not taken off as quickly in other Asian countries as they have in P.R. China, today there are over 40 million e-bikes sold each year globally, and the number continues to increase – including over 10 million sold per year in the ASEAN region (IEA 2019). As people learn more about their convenience, ease of use, low operational cost, and durability in countries such as India, Indonesia, Viet Nam and Thailand, the sales are bound to increase. In Viet Nam, over 400,000 electric motorbikes were sold in 2017, 30% over 2016, and operational prices were found to be 33% less than petrol-powered motorbikes (compared to 3.2 million petrol-powered motorbikes in 2017, which saw sales increase of 4.8% since 2016) (NNA Business News 2018).

In many countries, electric bicycles can be ridden without any drivers' license, meaning that they are very convenient for students and other young people to drive. However, students also

have low purchasing power meaning that they will spend as little as possible on an electric motorbike. Counterfeit motorbikes can be found in many markets that may be inexpensive, but also come with poor safety features including brakes that wear away quickly or never work properly at all, leading to severe safety issues. The author observes on a regular basis, drivers of commercial delivery electric two-wheelers in P.R. China that hang their feet at the side of the bikes to act as brakes in situations where they need to stop quickly – an obviously ineffective safety strategy.

From an emissions perspective, electric two- and three-wheelers have no tailpipe emissions other than tire wear, which in any respect is not currently monitored as an emission of vehicles. As a result, there is no need whatsoever for emission standards, emission equipment or emission testing. The main environmental risk posed directly by electric two- and three-wheelers arises through battery disposal. In countries where no battery recycling industry has evolved, lead-acid batteries discarded from electric two-wheelers can cause serious pollution in places where people dump them. Brake safety and fitness of onboard electronic controls on electric two- and three-wheelers can also be issues that are difficult to monitor and may in the future require periodic inspection to ensure that road users are not put at risk by improperly maintained vehicles. On the whole, however, electric two- and three-wheelers provide a major opportunity for all users to reduce exposure to pollution, reduce costs of testing and maintenance, and generally improve energy security.

In spite of the many social and environmental benefits of electric motorcycles or e-bikes, a total cost of ownership (TCO) analysis performed by the International Energy Agency determined that e-bikes are only cost-competitive with petrol-fuelled motorcycles in countries with high fuel taxes when mileage exceeds 4,500 km per year and battery packs cost less than USD 400 / kW-h (IEA 2019). As a result, policies that encourage adoption of electric two-wheelers and discourage purchase of petrol-fuelled vehicles are necessary in order to push the market towards electric vehicles. In many countries, a relaxed approach towards licensing of both drivers and vehicles (compared to conventional motorbikes) has been a boon to development of these vehicles. Additionally, policies that restrict the use of conventional two- and three-wheeled vehicles will push the adoption of electric vehicles quickly. Cities such as Guangzhou, Shenzhen and other cities implemented motorcycle bans in the early 2000's in order to reduce noise, pollution and even crimes that were resulting from out-of-control conventional motorcycle usage, while in many cases not including electric two-wheelers in

enforcement activities (Johnson 2006). It is important to note that some compensation was offered to owners of qualified conventional motorbikes, after accounting for depreciation of the vehicle.

Beginning around 2016, a number of Chinese cities started to reconsider electric motorbikes based on complaints about safety. The Ministry of Industry and Information Technology (MIIT 2018) noted that between 2013 and 2017 there were 56,200 road traffic accidents caused by electric bicycles, resulting in 8,431 deaths, 63,500 injuries and direct property losses of 111 million RMB (approximately 16.7 million USD in 2017). It was identified that such easy access to vehicles without licenses, training or enforcement was one cause for such a high accident rate, and therefore a stringent safety standard has been rolled out for new electric two-wheelers. Recently, after a legal review to consider either banning or managing electric two- and three-wheelers, Beijing has implemented a strict licensing system for electric 3-wheeled delivery vehicles, has required all electric two- and three-wheeled vehicles to become licensed, and will gradually phase-in the new safety standards. It is hoped that these actions will usher in a new phase of safe electric two- and three-wheeler use in the city.

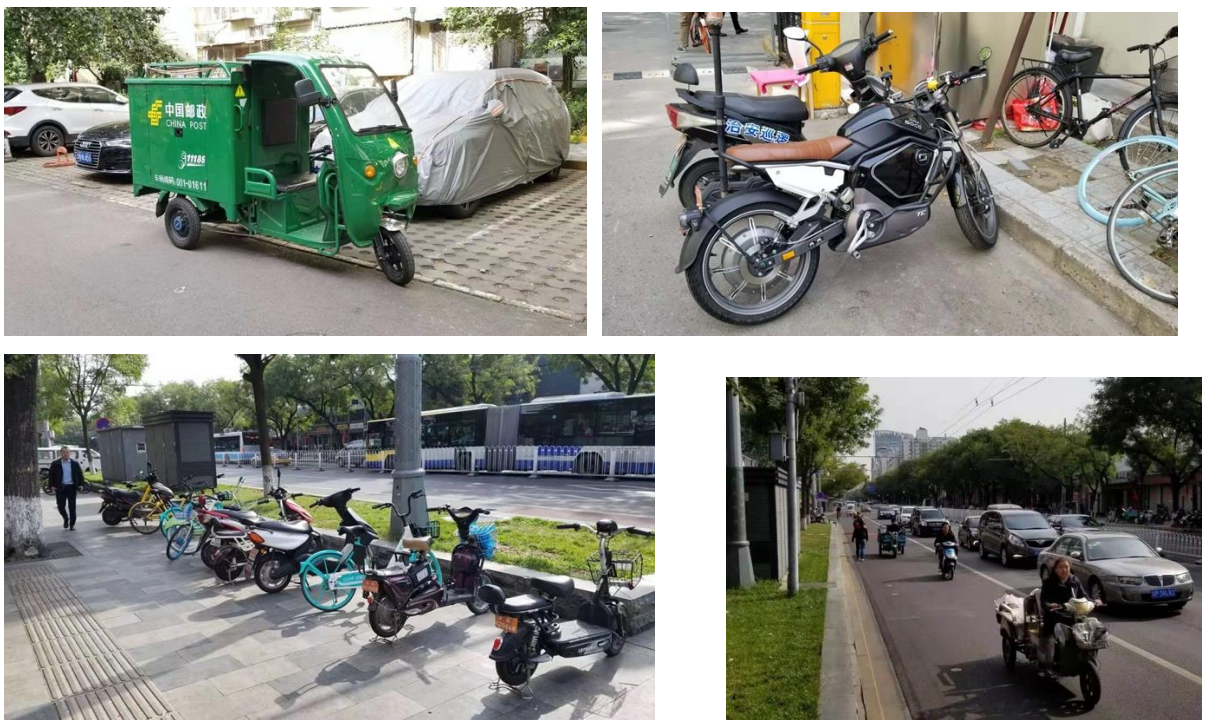


Figure 6 Various electrified two- and three wheelers in Beijing, China (Source: author)

Cars, Public transportation, Urban Delivery and Urban Services

City buses, urban delivery vans and cars are key as well to decreasing the need to provide I/M services for the transport sector. City buses, likely with the highest vehicle kilometers travelled (VKT) of all vehicles in cities are also the vehicles that face the highest risk of being gross emitters because of pressure to keep them in service, as well as for governments and operators to keep the costs of operation low – especially with respect to maintenance. Electrified buses, while expensive up front, are demonstrating that they have low operational costs due to the low price of electricity, and if implemented on a properly-planned route, can travel distances competitively with diesel and other city buses without any emission whatsoever.

Figure 7 Battery electric city buses in Beijing, China (Source: author)

Figure 8 An electric street sweeper in Beijing, China (Source: Author)

Figure 9 Mini and Sedan Electric Vehicles on-road in Beijing, China (Source: Author)

Today, P.R. China has the highest population of electric buses in the world. While the U.S. has a fleet of approximately 300, P.R. China is operating over 420,000 electric buses (Eckhouse 2019), and they can be observed in every city in China, both small and large, rich and poor. Other cities around the world are currently piloting e-buses, with the city of Paris recently ordering a fleet of 800, Bangkok planning a fleet of 35, and even Kathmandu planning to introduce a fleet of 300 electric buses to the city in order to attempt to bring down the city's air pollution levels (News18.com 2019).

5.0 Good practice

I/M is not a new concept, nor is it new operationally at a global level. Countries that are the home of vehicle manufacturers have been especially aggressive at having I/M systems in place, such as Germany, US, Canada, Japan, P.R. China and others because in addition to ensuring that vehicles are not polluting, there is an economic knock-on effect of maintaining vehicles, purchasing parts and service and eventually purchasing new vehicles after the old ones are scrapped. Indeed, in the first cases, I/M capacity may have arisen from economic and technical capacity to undertake such work that is a spin-off of automotive manufacturing, at least in part. GIZ (Kolke 2005) and Clean Air Asia (2016), based on observation of some of these countries, developed a core set of best practices for use in developing countries or any country that does not have an effective I/ M Program. The two reports noted above take different approaches to best practices in I/M setup and implementation. Kolke (2005) focuses on practical best-practices, while Clean Air Asia (2016) focuses more on the policy and regulatory framework needed in order to embed I/M programs in government and broader society.

The table below summarizes some of the key findings of these two reports:

Policy Framework			
	Centralized I/M systems	• A system of test-only stations for testing, and the network of existing repair garages for maintenance • Testing centres may be operated by the private sector, but must be certified and closely monitored by government • A transparent cost-recovery system can be implemented • Requires multi government agency planning in early stages, across levels of government • Links emission control I/M with road worthiness testing • Combines roadside and remote testing with periodic testing	• Cost effective to government • Allows best allocation of expensive testing equipment • Less prone to corruption • Inspectors receive proper inspector training, different than maintenance and repair • Opportunity to centralize vehicle database and provide data to government • Ensures that repair costs are based on market price rather than on risk of decertification • Certification is based on passing the test rather than on paying a certain amount to repair the vehicle.
	Comprehensive and recurrent fleet survey	• Understanding of the fleet allows for proper calibration of the I/M system	• Focus on continuous improvement in the fleet. As new vehicles become cleaner with new standards, ensure that the definition of gross polluters keeps pace • Linking automotive registration database to compliance data ensures on-road vehicles are accounted for and running, as well as a comprehensive understanding of vehicles in the jurisdiction.
	Timely and appropriate strengthening of I/M	• Effectively coordinate I/M expectations with emission standards of new vehicles, and update over time	• Take advantage of improved automotive technology over time to reduce emissions and improve fuel economy of the fleet
	Strengthen the vehicle maintenance and repair service industry	• Repair services operated independently from the inspection service	• As the government sets the requirements of the testing rather than the repair centre, there is market demand for better repair services. • Incentive to have better trained mechanics and comprehensive auto parts supply chain
	Consistent enforcement and reliable detection technologies	• Establish a program that builds and maintains public trust, awareness and participation by being fair, consistent and oriented towards safety and environmental protection	• Reduces program cost and increases implementation efficiency • Convinces vehicle owners and operators that maintenance is a real issue that can bring them benefits
	Complementing policies on vehicles that enter and exit the active fleet	• Ensure policies are in place to properly dispose of vehicles that cannot be brought into compliance and end-of-life vehicles • Design programs that encourage cleaner, more efficient or alternative energy vehicles in future purchases	• Avoid the transfer of end-of-life or unrepairable vehicles to rural or poor places where polluting vehicles will still impact people, but where enforcement is less likely to be undertaken on polluting vehicles • Ensure that future vehicles are cleaner than those that are retired, and ensure that infrastructure is available to operationalize them in society.
	Undertake public engagement in policy design	• Understand the challenges faced by various stakeholders in implementing I/M programs and undertaking vehicle maintenance	• An opportunity to inform vehicle users about good maintenance practices such as tire filling, using the correct lubricant, changing oil according to manufacturer recommendations, and paying attention to the OBD light for ensuring vehicle maintenance between inspections • Save energy and ensure automotive safety through regular maintenance

I/M Design: Best Practices

Understanding the automotive fleet is key to determining the scope of I/M in a country to ensure that proper inspection equipment is purchased, that testing methodologies and limits are properly developed, and even to ensure that inspection and maintenance skills are taught in technical schools and that supply chains for appropriate parts are available so that vehicles may actually be maintained.

Key components of the fleet characteristics that should be understood include (Clean Air Asia 2016):

- Vehicle type/make (e.g. motorcycles, 3-wheelers, light duty vehicles, heavy duty vehicles);
- Engine types and fuel (e.g. diesel, petrol, CNG/LPG, alternative drive train types such as hybrid, plug-in hybrid and electric vehicles with or without range extenders)
- Vehicles owned/used by private individuals, commercial entities, or government
- Vehicles used to transport people or goods by road.

For example, it is key to observe that motorized two- and three-wheeled vehicles are key to the automotive sector in many Asian countries, occupying up to 70% of the automotive fleet. Understanding the ratio of two-stroke to four-stroke to electric two-wheelers; understanding the emission standards of those vehicles (e.g. Euro III or Euro IV), and understanding the fuels used by those vehicles is key to designing an effective emission inspection system.

An intensive survey was undertaken by the Central Pollution Control Board of the Ministry of Environment, Forest & Climate Change of six major cities of India in 2015 that highlights the methodology and intensity of work necessary to properly understand the fleet of automobiles in the cities of Ahmedabad, Hyderabad, Kolkata, Lucknow, Patna and Solapur. The report begins with a description of each city, city structure and road maps, also describes the air quality in those six cities. A traffic survey was completed, including traffic volume counts, and parking lot/fuel pump surveys that helped researchers to compare the on-road, in-use situation of vehicle use with databases of registered vehicles as well as models for predicting vehicle use and default values used in emission prediction models. The survey found that the on-road vehicle use in all cities varied dramatically from the duty pattern used in models for predicting emissions from vehicles.

The researchers collected and summarized data on the types of vehicle on types of road:

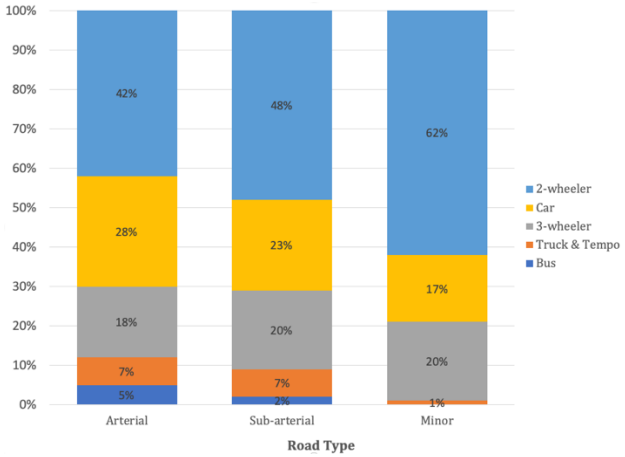


Figure 10 Distribution of vehicle types on different road types in Ahmedabad (Data source: CPCB 2015)

The vintage of each type of vehicle

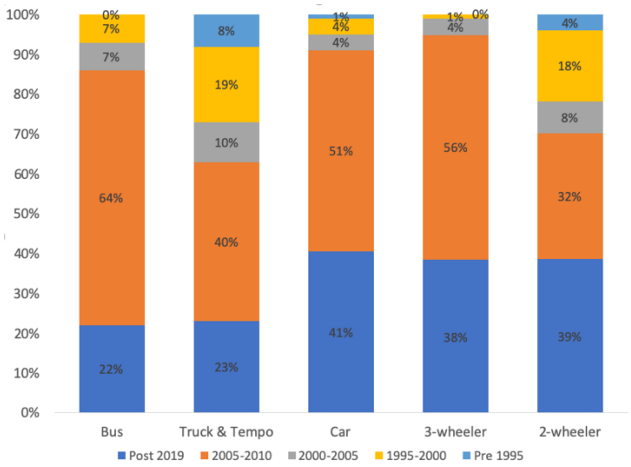


Figure 11 Vintage of Vehicles by Type in Lucknow, India 2015. (Data Source: CPCB 2015)

The daily km driven by each type of vehicle on average (VKT)

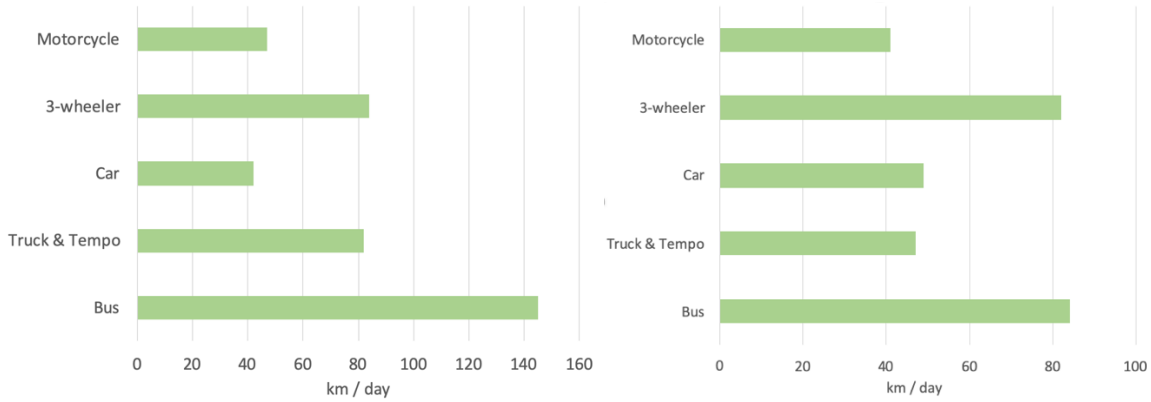


Figure 12 Daily Kilometers Travelled by Different Types of Vehicles in Kolkata (left) and Sholapur (right) (Data Source: CPCB 2015)

Average frequency in servicing of vehicles

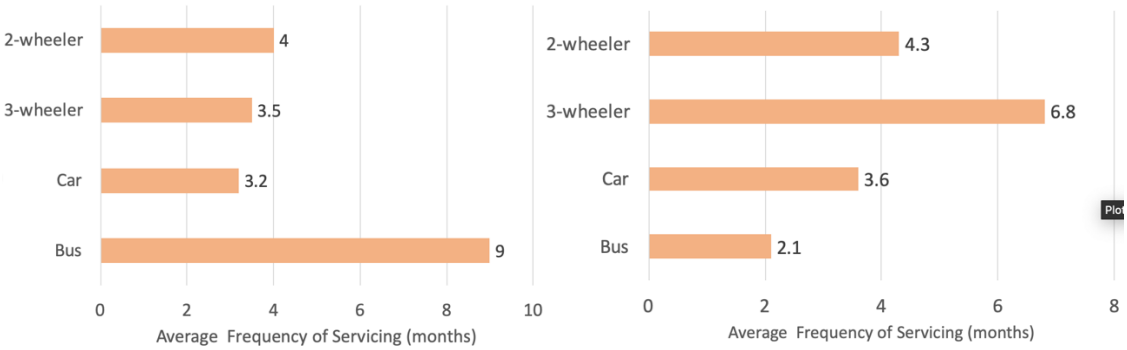


Figure 13 Average Frequency of Servicing Different Types of Vehicles in Patna (left) and Ahmedabad (right), India. (Data source: CPCB 2015)

The survey also measured other characteristics such as fuel type of each type of vehicle and average occupancy. Based on the survey, many conclusions can be made about the emissions from in-use vehicles in each city, as well as the requirements for I/M in those cities. Cities and countries in Asia can perform these kinds of surveys to ensure that they are properly capturing vehicles in their I/M programs.

Remote Detection of Heavy Emitters in China

Often, vehicles can suddenly become highly-emitting vehicles due to a broken part, an expired oxygen sensor in the engine, or being out of tune between emission checks, amongst other reasons. California called these vehicles "gross emitters", and noted that these vehicles which may only represent 10% of the vehicle population, could be responsible for up to 50% of pollution from the automotive sector. In California, they were discovered when researchers were measuring roadside pollution and found that even vehicles that had smog check stickers were emitting large amounts of pollution while on the road. Today, after the discovery of the "dieselgate" scandal at Volkswagen and other automotive companies, it is more important than ever to ensure that vehicles are emitting pollutants at a reasonable rate according to the standards at which they were certified. Now that cars can detect when they are being tested on a test bench, remote sensing is an important tool for ensuring that the worst emitters are kept off the road.

China is now the first country in the world to have established a national protocol for the remote sensing of heavy-emitting vehicles. The program is designed to capture the worst 5% of emitters using remote sensing equipment and cameras at fixed locations in cities.

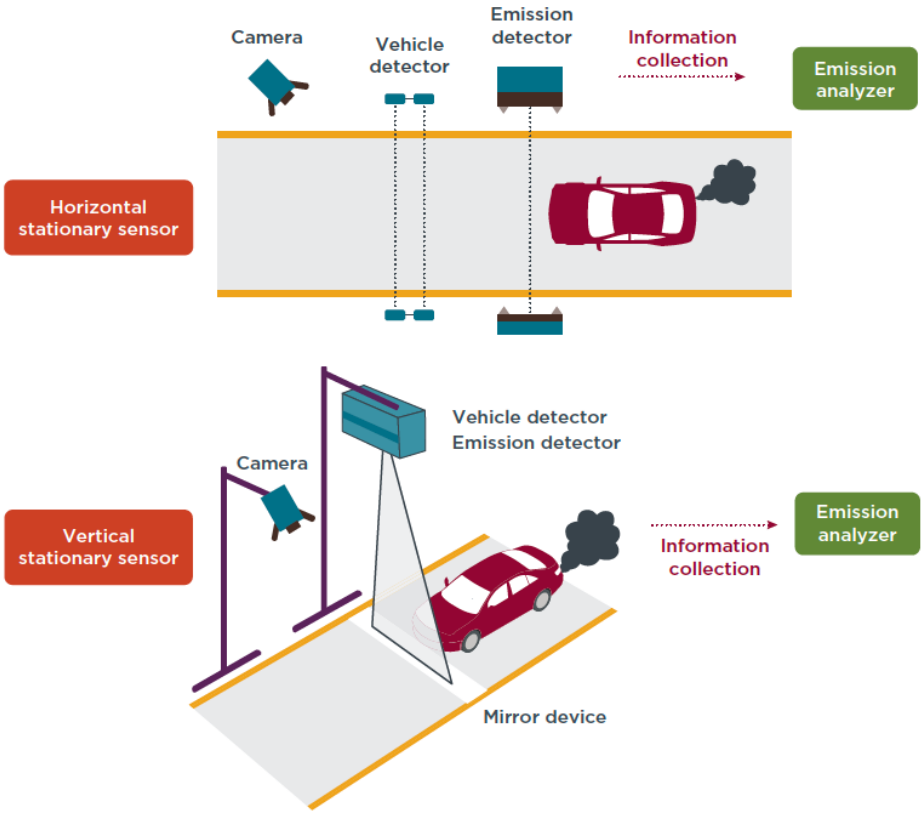


Figure 14 A conceptual diagram of a fixed location remote sensing device for vehicle emissions in China (Source: ICCT 2017)

While remote sensing has been used since 2005 in China to detect and reduce the number of high-emitting vehicles on the roads, by the end of 2016, about 70 cities had established remote-sensing programs to screen on-road vehicle emissions. This policy was devised to support and standardize the procedure for cities to undertake such enforcement.

It is required that equipment be installed no more than 5 m above ground level for vertical observation. For horizontal observation, the test light path must be positioned 20 to 40 cm above the road surface. The remote sensing equipment must include a global positioning system to collected locational data. Equipment should use an opacity test with a green LED with a wavelength of 550-570mm or equivalent, and the response of the test must be less than or equal to 1 second. Testing may only occur under the following conditions:

- No rain, fog, or snow; no obvious dust
- Wind speed: ≤ 5 m/s
- Environment temperature: –20° to 45°
- Relative humidity: ≤ 85%
- Pressure: 70 kPa–106 kPa

If a vehicle is found to be high emitting by a remote sensing device twice in 6 months, cities may have the option to require the vehicle to be maintained or to take other measures to ensure that the high emitting vehicle is no longer a high polluter. Emission limits for compression ignition engines are as follows:

Table 1 Emission limits for compression ignition engines

Pollutant	Limit
Opacity	30%
Ringelmann blackness	Level I (20%)
NO	1,500 x10^6

6.0 Major recommendations and conclusions

Inspection and maintenance of vehicles in Asia while at first glance seems like a simple issue is actually complicated, reaching across government departments and levels, across industries, and across socio-economic strata. Maintenance of vehicles is an expensive proposition no matter if vehicles are personally owned, owned by companies, or even owned by governments, and each group of stakeholders has motivation to avoid spending high amounts of money on maintenance if it is indeed possible. While societies need to strike a balance between environmental and economic burden by a vehicle owner, there are technologies and strategies that are making maintenance avoidance less possible than ever before in the past.

The fact is that I/M best practices are not new. As early as 1996, key recommendations for an effective I/M program were developed, including the structure as follows:

- A suitable test procedure, supplemented by inspection of Emission Control Systems
- Effective enforcement of Vehicle Compliance
- Adequate attentions to repair procedures

- Routine quality control
- Enforcement of proper enforcing guidelines
- Periodic evaluation, reviews and solution enforcements
- Minimization of repair costs and access to subsidies and exemptions on repair parts.

These recommendations still ring true today. What has changed is the technology now available to automotive manufacturers, governments and testing facilities to ensure that I/M is properly undertaken.

On-Board Diagnostic System Linkage to I/M

One key technology that can be immediately harnessed for I/M in Asia and the Pacific region is OBD. Nearly all new cars and trucks are mandated to contain a standardized OBD lamp which indicates if there are any problems with the emission control system, as well as a port that can be read with a hand-held terminal to understand what the problems might be, and to ensure that the OBD system itself is working properly. All car and truck I/M systems should make use of the OBD system and check the OBD system for regulatory compliance, and cars and trucks where the OBD light is on should be repaired before they can be recertified as road worthy.

Unfortunately, OBD systems have not evolved as smoothly for two-wheeled vehicles such as motorbikes. Even though motorbike Euro 4 and Euro 5 standards contain requirements for OBD systems, it has been found by manufacturers and users that OBD cannot be easily ported from cars and trucks due to different operational and physical properties of motorbikes, such as a motor with much higher RPM, and the fact that the mass of motorbikes is much less than cars and trucks, meaning that road bumps and other interruptions to the momentum of the vehicle in motion can directly affect the motor and other parts of the motorbike in ways that might affect OBD sensors (Purvis 2019). While the existing OBD systems, especially for more expensive and larger-engine motorbikes should be checked, in addition to exhaust testing, more research needs to be done on OBD for motorbikes.

Centralized data reporting and analysis

Second, more work needs to be done to centralize data from automotive I/M in Asia. Although testing data may be sent to a central server for tracking, data transmission needs to be automated

from the testing equipment to ensure that there is little opportunity for test operators to make mistakes or intentionally enter incorrect data to the system manually. Corruption at testing centers is an issue in some countries and automated data reporting can help to reduce this problem. Additionally, improved auditing of test facilities can help ensure that test results are consistent with the actual emission performance of cars. The strongest way to ensure that test facilities are performing well, however, is through a well-structured centralized database. A centralized database should collect the core data from automotive testing including:

- Vehicle type
- Fuel type
- OBD status
- Emission levels (according to vehicle and fuel type)
- Vehicle identification number (VIN)
- Equipment identification number
- Test operator identification number
- Testing center identification number

Amongst other data, these indicators can help to observe the on-road fleet and compare the on-road fleet with the registration database. By collecting and centralizing data about the testing equipment and personnel, comparisons can be easily made between different operators and testing stations to see if there are discrepancies and to understand if additional testing equipment improvements, training or enforcement might be required in order to ensure that vehicles are properly tested, maintained and operated.

High-quality centralized data can also help to ensure that emission limits for in-use vehicles are stringent enough to find gross emitters. By observing the long-term trends for different vehicle and fuel types, it can be determined if too many cars are passing the test, and if necessary, the emission limits can be recalibrated to ensure that vehicles are being discovered as gross emitters and properly repaired.

Roadside remote sensing

Roadside remote sensing is also becoming a tool for monitoring and enforcing inspection and maintenance systems. Remote sensing systems can be extremely useful as a passive method for detecting gross emitters while vehicles are in operation. In the best-case scenario, remote

sensing systems are linked to cameras that can detect the license plate number of the car, and compare the emission status of the vehicle to the most recent vehicle emission testing record. If a vehicle has been recently passed by a testing centre, but is found to be a gross-emitting vehicle on the road, then an inquiry can be made into why the vehicle was recertified, and if there are any problems at the vehicle testing facility. Automated systems are preferred because manual remote monitoring systems can fall into dis-repair or become unused because emission enforcement may be a lower priority compared to traffic safety for enforcement officers, or because the effort of catching on-road offenders may be perceived to be greater than the reward. Today, automated systems are become more affordable and widespread as image recognition becomes a more mature technology.

Education and literature for automotive users

While inspection is an important policy mechanism for ensuring that vehicles are performing according to their emissions specifications, public education about automotive maintenance is a very important tool for ensuring that people take care of their vehicles. Public information can come in several forms:

1. Public information about the pollution that comes from vehicles. Road signs, billboards or media announcements letting the public know about the contribution of poorly maintained vehicles to the air pollution that affects their family's health is an important motivator for people to maintain their vehicles. Providing information about the financial cost of a poorly maintained vehicle due to wasted fuel is also an excellent message to motivate people to check and maintain their vehicles
2. Information about simple or low-cost maintenance that individual car owners/drivers can do to save fuel and reduce emissions, such as maintaining tire pressure or cleaning battery terminals is extremely valuable. Many car owners may not be aware that they can improve their fuel efficiency 7-10% by undertaking simple and low-cost regular maintenance. Information that helps drivers understand the major fuel consumption impact of keeping unnecessary items in their vehicle as dead weight can make an immediate and cost-free improvement to fuel consumption and emissions. More advanced information such as using the vehicle- and climate-appropriate oil or regularly replacing oxygen sensors on the vehicle can be posted at I/M centres, fuel stations or garages to let drivers know that they can save yet more fuel and money by undertaking these types of regular maintenance, even without inspection.

Driver education is a low-cost and efficient means of ensuring on-road vehicles are performing well, no matter if they are cars, trucks, motorbikes, scooters or even bicycles. They will also help drivers to know more about their vehicles and understand the impact of their own vehicle on air pollution and climate change.

Electrification

Although electrification of transportation is not mature in most places around the world, it is an obvious direction in the trend of automotive technology. Fully electric vehicles do not have tailpipe emissions and therefore do not require I/M systems to check their emissions. Governments should carefully assess their approach to electrification from an I/M perspective. For example, fully battery electric vehicles have no emissions, but hybrid, plug-in hybrid and range-extended electric vehicles all have fuel-burning motors on-board that could be out of tune and grossly emitting. It is important for governments to properly account for these vehicles in the context of emissions testing and maintenance. In the meantime, I/M databases can inform governments where the focus of their electrification program could be. Vehicles that tend to have the worse emissions performance could be the focus of electrification pilot projects. This could especially apply to commercial vehicles such as taxis and buses, particularly in cases where they burn diesel.

Perhaps the best place for governments to start an electrification push is in the area of electric two- and three-wheelers. It has been demonstrated across P.R. China that electric bikes, scooters and motorbikes can effectively replace fuel-burning engines in a variety of topographies, from the cold and flat northern areas of China, to the hot an hilly mountainous regions in western China, to the tropical areas of Guangdong and Hainan island. Electric two- and three-wheelers have a mature supply chain, reliable technologies, and have clear economic and emission advantages over their fuel-powered predecessors. Cities with reliable power sources can focus on policies for high-speed replacement of fuel-powered two- and three-wheelers with electrified ones for immediate reduction of air and noise pollution.

7.0 The way forward

Inspection and maintenance of vehicles is approaching a curious time in history. While many old vehicles exist on the roads of countries in Asia and the Pacific, and even many new vehicles are sold with low-technology emission control systems, new technology is evolving quickly that directly affects the way that I/M is conducted and the effectiveness that it can achieve. In

vehicles, OBD systems are quickly evolving to allow vehicle inspections to take place quickly and efficiently without expensive testing equipment – using technology that is already present in newer vehicles. OBD systems can report on the status and operation of the vehicle and indicate when vehicles require maintenance at a testing center. OBD systems also make vehicle users aware of when their vehicle requires maintenance in order to continue operating ideally.

OBD systems can be of great use to regulatory agencies for ensuring vehicles are compliant, but even this technology is evolving. First, regulators will need to ensure that the OBD systems are truly serving their purpose of ensuring proper operation of the vehicle to reduce emissions and fuel consumption. Recent realization that automotive companies have cheated on emissions testing, especially of diesel vehicles, should raise the alarm that they are not necessarily trustworthy partners. As such, OBD systems need to be carefully investigated to ensure that they report correct data when cars are being inspected and certified. As a result, while OBD data may be very useful, vehicles should still be tested

The advent of electric vehicles at first glance suggests that the days of annual and in-use inspection of vehicles will soon come to an end. Yet such an end is actually very far in the future in most countries and still requires a strong push in order to protect the public from automotive emissions, particularly when people live and work close to motorways.

As such, several major pathways lead the way forward:

1. Even in countries with advanced policies for electrification of personal transport vehicles, it will be decades until the mixture of EV automotive sales and retirement of conventional vehicles will result in a transport sector that does not emit pollution. It is very clear that regulatory agencies will need to build up and maintain inspection and maintenance systems long into the future. Yet electrification is a near-term solution of air pollution especially for two- and three-wheeled small vehicles. The experiences of P.R. China are extremely valuable and instructive for countries in reducing the overall burden of testing and maintaining petrol or LPG burning vehicles. Even though consumers may not be familiar with electric two- or three-wheeled vehicles, they are indeed becoming mainstream technologies with over 250 million of the vehicles on the road in China alone, in all sorts of climactic and topographical conditions.

2. Some aspects of I/M are still not working – OBD checks are not being included in testing in some countries, centralized databases are not as effective as possible in ensuring the integrity of testing systems and equipment, and corruption is still a tool for individuals to avoid spending money on maintaining their vehicles. The I/M system is an excellent tool for governments to better understand the emissions from the transport sector, and through better data collection, emission limits for in-use vehicles can be adjusted to ensure that public health is protected from this pollution, and that drivers benefit from the better fuel economy that comes from a better maintained vehicle.

3. Governments can make better use of remote sensing to detect gross emitting vehicles at the roadside. Remote sensing can help to process large numbers of vehicles without requiring them to stop and be tested with roadside equipment. These systems can save on the amount of staff required for roadside emission testing, do not require traffic to be disrupted, and can use relatively inexpensive sensors. Remote sensing technology has evolved to the point that individual vehicles can be detected and photographed if they are found to be gross emitters. Based on photographs, regulators can identify the vehicle and follow-up to ensure that maintenance is performed on the vehicle. Regulators can also use this data to establish the effectiveness of their fixed I/M programmes.

Inspection and maintenance of vehicles will be very important into the foreseeable future. While automotive companies are beginning to roll-out electric versions of many of their car and truck models, most do not plan to produce electric vehicles on scale until 2030 or beyond. In the meantime, on-road vehicles will continue to operate, to get older, and to require tune-ups and maintenance. Even high-tech hybrid vehicles will require maintenance to ensure conformity with in-use emission standards, and therefore will require inspection. It is key that governments invest in these systems and make use of them to inform drivers about regular vehicle maintenance, and where necessary force them to take action to maintain their vehicles and protect the public from unnecessary air pollution and GHG emissions.

8.0 Topics for discussion at the EST Forum

How will the role of I/M change over time as transportation becomes electrified? What will be the future priorities of I/M?

What are the main barriers to electrification of two- and three-wheelers? What are the risks in each country, how can those risks be mitigated, and how can electric two- and three-wheelers be promoted?

How can I/M be made less susceptible to human intervention in Asia and the Pacific, and ensure that cars truly remain as clean as they are capable of being?

How can finance be mobilized in places of poverty to ensure that vehicles are well-maintained?

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