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Identifying a solution that promotes vehicle emission management programs in developing nations by implementing proven and low-cost techniques.

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Emissions from cars, trucks, and other mobile sources are significant sources of hazardous air pollutants (HAPs) and greenhouse gases (GHGs). The United States and Europe established standards to limit tailpipe emissions from vehicles as early as 1964. While many developing countries do not have the same history of environmental enforcement and analysis as the United States and other developed nations, they can take advantage of lessons learned and low-cost compliance actions to immediately improve air quality.

Inspection and maintenance (I/M) programs that enforce emission limits offer one of the best opportunities to reduce emissions for in-service vehicles. Unfortunately, many countries do not have adequate I/M programs. The purpose of this article is to promote implementation of vehicle emission management programs in developing nations to reduce the harmful effects associated with traffic-related pollution using low-cost, proven techniques. The methodologies given below can be implemented without expensive attainment studies, using the results and recommendations from existing programs as the basis to begin.

Each year, an additional 40 million cars and trucks are added to the more than 1.1 billion vehicles already in service around the world. Most new vehicles are designed to meet strict emission standards established by the European Union (EU) or the United States. Other manufacturing countries, such as Japan, China, India, and Brazil, have adopted similar strict emission standards for new vehicles. In 2013, the United Nations Working Party on Pollution and Energy approved the World Harmonized Light-Duty Vehicles Test Procedure (WLTP) to standardize emission tests. Prior to the WLTP, different protocols were in place to evaluate compliance requiring manufacturers to conduct multiple test cycles.

Testing protocols to meet these standards typically involve large dynamometers and laboratories, and are the burden of manufacturers. For vehicles already in service, emissions reduction programs include insuring proper maintenance, improving driver behaviors, enhancing fuel quality, and implementing traffic management systems to avoid congestion, as summarized in Table 1.

Some vehicle emission management programs exempt certain vehicles from emissions testing based on age (e.g., historic vehicles), type (e.g., hybrids or motorcycles), weight (e.g., > 14,000 lb), or use (e.g., farm/agriculture). Non-exempted vehicles must undergo evaluation every one to three years to legally operate on public roads. These tests typically include a combination of procedures shown in the “Vehicle Maintenance” column of Table 1.

### Vehicle Emission Tests

#### Visual Inspections

Visual inspections confirm that vehicle pollution control technologies (PCT) have not been tampered with. Visual inspections also allow initial screening of vehicle performance by identifying heavy exhaust smoke and fuel smells if present. The most common PCT on vehicles is a catalytic converter that oxidizes unburned fuel from the exhaust; other PCTs that could be subject to inspection include the positive crankcase ventilation (PCV) valve and fuel caps. Fuel cap meters can be used to test the sealing capacity of the cap.

Visual inspections do not determine whether the technology is working properly and require substantial knowledge from inspectors due to the wide variety of vehicles and technologies.

<table>
<thead>
<tr>
<th>Inspection/Maintenance</th>
<th>Driver Behavior</th>
<th>Fuel Quality</th>
<th>Traffic Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Visual Inspections</td>
<td>• Limited Idling</td>
<td>• Reduced Sulfur</td>
<td>• Smart Traffic Controls</td>
</tr>
<tr>
<td>• Idle Exhaust Testing</td>
<td>• Reduced Aggressive Driving</td>
<td>• Clean Fuels</td>
<td>• New Bypass and Road Design</td>
</tr>
<tr>
<td>• Fuel Cap Testing</td>
<td>• Enforced Moving Violations</td>
<td></td>
<td>• Improved Road Surfaces</td>
</tr>
<tr>
<td>• On Board Diagnostic (OBD) Evaluation</td>
<td></td>
<td></td>
<td>• Flexible Work Hours</td>
</tr>
<tr>
<td>• Opacity Testing</td>
<td></td>
<td></td>
<td>• Carpooling</td>
</tr>
</tbody>
</table>

Table 1. Non-manufacturer-related methods to reduce vehicle emissions.

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variety of vehicles. As a result, ineffective inspections may take place. In Mexico, for example, more than 50% of inspected cars were found to have received fraudulent or incomplete inspections.14

**Idle Exhaust Testing**
Emissions from light road vehicles (LRVs) using gasoline are often measured using a two-speed idle (TSI) test with an emissions exhaust meter. The first, or low idle speed, is the normal idle state of the vehicle at rest. The second, or fast idle speed, is measured at 2,500 RPM. The maximum limits for gasoline LRV in the United States15 are shown in Table 2.

The United Kingdom uses a similar TSI test.16 Emission limits are based on the type and model of the car, but range from 0.2–0.5% for low idle carbon monoxide (CO) and 0.2–0.3% for fast idle CO. Hydrocarbons are only measured at the fast idle speed and may not exceed 200 parts per million (ppm), while the fuel/air ratio (lambda) can range from 0.91 to 0.97. A typical TSI test kit weighs less than 5 lb (2.3 kg) and costs approximately US$6,000.

The use of TSI testing is being challenged. Regulatory agencies are instead relying on the on board diagnostic (OBD) test to provide a more comprehensive evaluation of the state of the vehicle's emission system.

**Opacity Testing**
Vehicles with diesel engines use exhaust smoke opacity tests. The measurement units are in light absorption coefficient (m⁻¹) or smoke density (%). Opacity meters measure light extinction as exhaust gas passes through a light beam.17 The light wavelength is selected to prevent absorption by specific gas components and allow scattering by aerosols as small as 50 nm.18 Table 3 presents the EU smoke limits for different types of diesel engines.19

The United States uses the SAE J1667 Snap Acceleration Test standard for heavy road vehicles (i.e., > 8,500 lb).20 Limits are based on the year of vehicle manufacture, as shown in Table 4.

### Table 2. Emission limits for light road vehicle gasoline engines.

<table>
<thead>
<tr>
<th>Idle Speed</th>
<th>Minimum Sampling Time (sec)</th>
<th>HC (ppm)</th>
<th>CO (%)</th>
<th>Lambda (Fuel/Air Ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>30</td>
<td>100</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Fast</td>
<td>30</td>
<td>100</td>
<td>0.5</td>
<td>0.97–1.03</td>
</tr>
</tbody>
</table>

### Table 3. Smoke density limits for different types of diesel engines.

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Smoke Density (m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Turbo Charged</td>
<td>2.5</td>
</tr>
<tr>
<td>Turbo Charged</td>
<td>3.0</td>
</tr>
<tr>
<td>Built to EURO 4 or higher</td>
<td>per manufacturer (not to exceed 1.5)</td>
</tr>
</tbody>
</table>

### Table 4. Smoke density limits for heavy road vehicles.

<table>
<thead>
<tr>
<th>Year of Manufacture</th>
<th>Maximum Opacity Limit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1991</td>
<td>55</td>
</tr>
<tr>
<td>1991 and Later</td>
<td>40</td>
</tr>
<tr>
<td>Buses</td>
<td>30</td>
</tr>
</tbody>
</table>

### Table 5. Pass/fail criteria for OBD-enabled vehicles.

<table>
<thead>
<tr>
<th>Vehicle Model Year and Type</th>
<th>Pass Criteria</th>
<th>Fail Criteria</th>
</tr>
</thead>
</table>
| 1998–2000 OBD-enabled vehicles | No Fail criteria detected | • Vehicle OBD computer is unable to communicate with OBD emissions test unit  
• 3 or more supported readiness monitors not set to “Ready”  
• Malfunction Indicator Light (MIL) is commanded “ON” with Diagnostic Trouble Code (DTC) |
| 2001 and later OBD-enabled vehicles | No Fail criteria detected | • Vehicle OBD computer is unable to communicate with OBD emissions test unit  
• 2 or more supported readiness monitors not set to “Ready”  
• MIL is commanded “ON” with DTC |
Programs using opacity testing have been shown to be effective in reducing emitted pollutants despite not showing strong correlation to particulate matter and carbon monoxide. Opacity tests can be conducted either at fixed test centers or at random road side check points due the portability of test kits. A typical test kit weighs approximately 25 lb (11.3 kg) and costs approximately US$5,000.

**On Board Diagnostics (OBD) Testing**

The California Air Resources Board (CARB) has mandated OBD systems for all vehicles sold in the state since 1988. The U.S. Clean Air Act of 1990 expanded the OBD requirements (OBD II) and enforced implementation in all new light-duty cars and trucks from 1996. The OBD II system monitors the emission performance of a vehicle and tracks malfunctions. A technician can access stored information with an OBD reader. The pass/fail criteria in Table 5 shows basic features of the OBD II in regards to an I/M program.

**Keys to Effective Testing Management**

Lessons learned from a World Bank study in Mexico found that testing procedures must be performed within an effective management approach. Key elements of a successful vehicle emissions program should include:

1. **Dedicated testing center.** Centers should test emissions and not repair discrepancies to avoid conflict of interest.
2. **Multiple testing centers.** Centers should be conveniently located for easy access.
3. **Effective test certificate enforcement.** Testing certificates should be issued or easily tracked by enforcement staff. Enforcement should be authorized to a wide enough body of public agents to allow for effective oversight. This may mean allowing local police to issue citations if a certificate is out of date, as compared to only allowing the environmental regulatory agency sole jurisdiction.
4. **Rigorous procedures.** Testing procedures should be rigorous enough to prevent vehicles from circumventing passable standards.
5. **Independent testing center reviews.** An independent third party outside of the responsible agency should be assigned to review each test center to insure it is properly and consistently conducting test procedures with trained personnel.
Table 6. Example costs for I/M tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Equipment</th>
<th>Estimated Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Inspection</td>
<td>Fuel Cap Tester</td>
<td>600</td>
</tr>
<tr>
<td>OBD</td>
<td>OBD Reader</td>
<td>500</td>
</tr>
<tr>
<td>Snap/FAS Test</td>
<td>Opacity Meter</td>
<td>5,000</td>
</tr>
<tr>
<td>TSI Test</td>
<td>Tailpipe Meter</td>
<td>6,000</td>
</tr>
<tr>
<td>Total I/M Station Costs</td>
<td></td>
<td>12,100</td>
</tr>
</tbody>
</table>

The EU developed its own OBD system, E-OBD, and has mandated it in all new M1 category cars (i.e., <2,500 kg) since 2002. Other countries adopted modifications of OBD II, including Japan, Brazil, China, India, and South Korea. Vehicles with OBD II, EOBD, or the Japanese OBD variant systems are likely to meet the requirements of most countries.

Recommendations

A simplified I/M process is shown in Figure 1. Categorizations such as exemptions and weight classes are not considered in order to emphasize that a low-cost, simple program is more sustainable and widely accepted by vehicle operators than a complex system that is ambiguous or unenforceable. For environmental authorities developing or enhancing a vehicle I/M program, the key tests, in order of cost and effectiveness would be:

1. visual inspection with pass/fail criteria with at a minimum checks for positive crankcase ventilation valves, fuel cap, and catalytic converters;
2. OBD test for vehicles equipped with an OBD system; and
3. two-step idle test for gasoline fuel vehicles that do not have an OBD system or cannot take the OBD test due to incompatible formats.

The cost to equip an inspection station is relatively inexpensive, as shown in Table 6. For example, if only the OBD tester is used with visual inspection, a minimum cost of only US$600 is required. Other supporting costs required for a successful I/M program, such as a national data management system to track inspection results, real estate costs for inspection centers, staff wages, training and certification programs, as well as audit protocols, were not included.

References

20. J1667 Recommended Practice—Snap Acceleration Smoke Test Procedure for Heavy-Duty Powered Vehicles; Society of Automotive Engineers (SAE), Warrendale, PA, 1996.