THE REAL URBAN EMISSIONS INITIATIVE

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BRIEFING

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Use of remote-sensing technology for vehicle emissions monitoring and control

Measurement of exhaust emissions from vehicles during normal, on-road operation is key to any effective system for controlling air pollution in the transportation sector. It is essential to detecting discrepancies between certification-test performance and actual, "real-world" vehicle emissions, whatever the cause of the performance gap—equipment failure, normal deterioration with use, or deliberate efforts to cheat regulations. It offers a means of making certification-test protocols more robust and the results more in line with real-world performance. It gives regulators and researchers insight into both transportation's contributions to local air-quality problems and the effectiveness of policies intended to mitigate those problems.

The most widely known method of in-use vehicle emissions testing employs a portable emissions measurement system, or PEMS. This involves sampling and analyzing tailpipe exhaust with equipment mounted on an individual vehicle as it is driven over the road or on a closed course, and produces a detailed, second-by-second record of emissions from that single vehicle. PEMS is widely used by researchers. It played a key part in detecting widespread evasion and cheating of vehicle emissions regulations by manufacturers, and has been incorporated into certification-test protocols for both heavy-duty and light-duty vehicles. But it is time consuming and expensive. And, while PEMS is less susceptible to cheating or gaming than a lab-based chassis-dynamometer test, it is possible for a modern vehicle to "know" that it's being tested and react by changing the engine calibration and emission controls even with a PEMS setup. For these and other reasons PEMS is not inherently well suited to fleet monitoring and surveillance.

Remote sensing as a means of measuring motor vehicle emissions is less well known, though it is a well-established research technique in that area as well as others, and like PEMS has been successfully deployed by vehicle emissions regulators. Compared to PEMS testing it is less expensive in terms of both time and money. That plus

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the unobtrusive ("remote") nature of the technique make it well-suited to fleet monitoring. More generally, the basic characteristics of the data collected by the two methods—detailed second-by-second data on an individual vehicle or small number of selected vehicles from PEMS, one-second or half-second samples from a potentially very large number of vehicles from remote sensing—show them to be complementary tools that, deployed together, can produce a more precise and detailed understanding of not only pollutant emissions from on-road transport but also policy performance.

This briefing is a concise introduction to the use of remote sensing in regulating and controlling pollution from on-road vehicles.

REMOTE SENSING BASICS

Remote sensing systems use absorption spectroscopy to non-intrusively measure pollutant concentrations in the exhaust plumes of in-use vehicles. A light source and detector are placed either beside or above a roadway, with the instrument oriented so that the light beam produced by the source traverses the exhaust plumes of vehicles passing. Pollutants interact with light in well-understood ways, so the relative amount of these species present in the vehicle exhaust can be determined by measuring how much light of certain wavelengths is absorbed as the light beam passes through the plume. Each remote sensing measurement lasts for less than one second and, when successful, yields an estimate of the concentration of pollutants relative to the concentration of CO_2 in the exhaust plume. Remote-sensing systems measure nitrogen monoxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2). Particulate matter (PM) emissions are measured indirectly using plume opacity. Sulfur dioxide (SO_2) and ammonia (NH_3) emissions can also be measured using remote sensing.

Emissions data is of limited utility if it cannot be linked to information about the vehicle it comes from, including how the vehicle is being operated at the time of the measurement. Remote sensing systems incorporate additional equipment to acquire this information. A camera records an image of vehicle's license plate number, which can be used to retrieve vehicle specifications (e.g., make, model, fuel type, engine size, emission standard) from registration databases. Another device measures the speed and rate of acceleration of the vehicle, which provides information about the vehicle's engine load at the time of emissions measurement. Finally, sensors measure ambient conditions, such as temperature, pressure, and relative humidity.

A complete remote sensing record for an individual vehicle contains the following information:

» the concentration measurement of each emission species relative to CO_2 above the concentration in ambient air

» the vehicle's speed and rate of acceleration

» the measurement conditions: road grade, ambient temperature and pressure, and relative humidity

» description and specifications of the vehicle, including brand, model, category, model year, body type and size, fuel type, engine size, emission standard, type-approval CO_2 value, and empty vehicle mass

There are at present two main commercial suppliers of remote sensing equipment and testing services in the United States and European Union: Hager Environmental and Atmospheric Technologies (HEAT) and Opus Inspection.[1] Each of these companies has developed remote sensing systems that follow the general principles described above. However, there are important differences in the measurement approaches applied by the two companies. The most readily apparent difference between the two, illustrated in Figure 1, is the placement of the light source and detector units in relation to the roadway. The current generation of the Opus instrument, the RSD5000, applies an across-road geometry, where the instrument is placed at the side of the roadway and the light beam crosses horizontally through the exhaust plume. In contrast, the HEAT EDAR remote sensing instrument is positioned above a roadway with the light beam passing vertically through the exhaust plumes of test vehicles. In a practical sense, the top-down geometry of the EDAR instrument makes it easier to make measurements at sites with multiple lanes and makes the measurement less sensitive to the height and orientation of the test vehicle's tailpipe. On the other hand, the roadside positioning and portability of the RSD5000 support relatively rapid set-up and increase the deployment flexibility of the instrument. The HEAT EDAR instrument is further distinguished from the Opus RSD5000 in its use of a laser as a light source. The laser is swept across the width of the roadway, allowing for measurement of the entire vehicle exhaust plume. While the EDAR remote-sensing instrument has been commercialized only recently, versions of the Opus across-road remote-sensing technology have been in use for multiple decades.

1 Opus Remote Sensing Europe (RSE) is the European subsidiary of Opus Inspection.

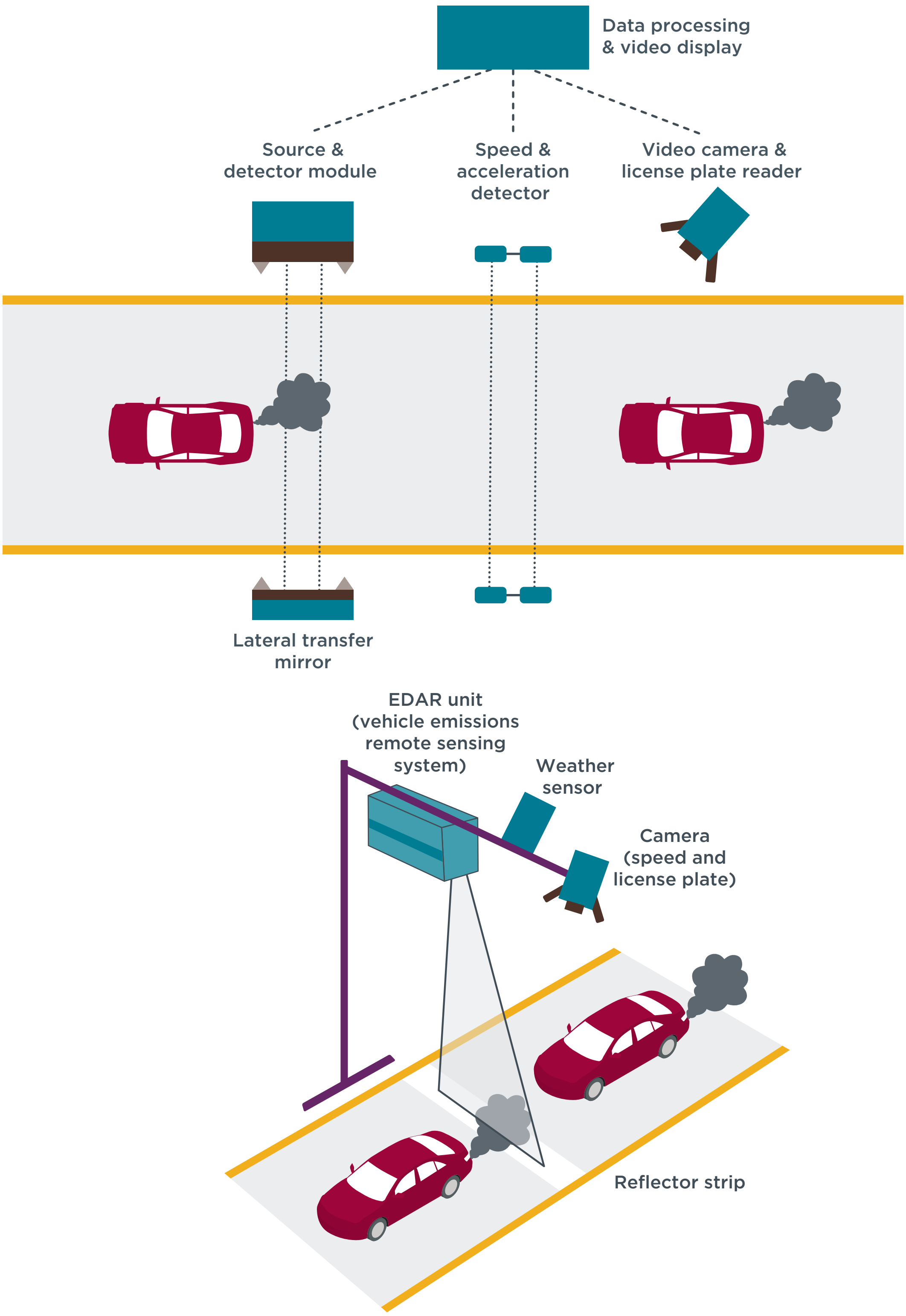

Figure 1. Schematic setup of the three units of the remote sensing device. Top, setup for cross-road remote sensing: the light source with the reflecting mirror at the other side of the road and the light detector; the speed and acceleration detectors; and the number plate recorder. Bottom, setup for top-down remote sensing system (EDAR).

A market is emerging for remote-sensing technology in China, spurred by national and local governmental efforts to establish remote sensing networks to support vehicle emissions control programs. Domestic suppliers there have also developed remote-sensing systems to meet this growing demand.

REMOTE SENSING DATA ANALYSIS

Compared to a PEMS test, a single remote-sensing record provides a limited amount of data about the emissions performance of a vehicle. The remote-sensing sample lasts for less than 1 second, and measured emissions are representative of a single driving condition, as defined by the vehicle's speed and acceleration and the road grade. The remote sensing test is comparable to a second's worth of data from a PEMS test, which can last for up to several hours.

The short test length should be seen as a feature of the remote-sensing method, rather than a limitation. The approach enables the measurement of real-world emissions from a very large number of vehicles in a short period of time and a cost-effective manner. A single remote-sensing instrument can measure the emissions of thousands of vehicles each day. While each individual measurement is only a snapshot of the emissions from a single vehicle, the aggregate sample can provide detailed information on emissions from not only the measured fleet but also specific subgroups within it. If remote-sensing measurements are made at multiple locations in an urban area, or even at locations in disparate geographic regions with similar vehicle fleets, the combined dataset can offer a rich perspective on real-world emissions performance over a range of driving and ambient conditions.

The direct output of a remote-sensing measurement is the concentration of a given pollutant in the test vehicle's exhaust plume relative to the CO_2 concentration in the exhaust. This value is typically converted to a fuel-specific emission factor, which is a measure of the mass of pollutant emitted by the vehicle per mass of fuel burned (grams per kilogram of fuel, g/kg). Methods have been developed to further convert fuel-specific emission factors to distance-specific emission rates (grams per kilometer, g/km) in order to compare against regulatory limits and emission factor models. So far, these methods have only been applied to aggregate samples of remote-sensing records for specific vehicle groups, not to individual vehicle samples.

Most analyses of remote-sensing data aggregate individual vehicle emissions records to evaluate emissions for specific groups of vehicles. These groupings can, for example, be by vehicle type, fuel type, certified emission standard and/or model year, manufacturer, and model or vehicle family. If sufficient data are available, further analysis of how emissions for each subgroup vary by engine load or ambient temperature can be performed. Generally, the finer the degree of granularity of analysis, the more remote-sensing data are needed to deliver statistically robust results. For example, a much greater quantity of data would be required to evaluate the average emission rate of Euro 6 diesel passenger cars made by a specific manufacturing group than would be needed to compare the average emissions of diesel and petrol passenger cars operating in a given urban area.

Remote sensing and PEMS can both be used to measure real-world emissions from motor vehicles. Each method has advantages. For example: Remote sensing could cost-effectively identify a vehicle model that might have a systematic defect in an emissions control system component by detecting a spike in emissions from thousands of individual vehicles of that model after they reach 50,000 kilometers, Conversely, a PEMS setup could allow regulators to determine that a particular vehicle model is illegally changing the performance of the emission controls at a certain operating temperature threshold by testing a small number of individual vehicles of that make/model exhaustively and demonstrating that all make the same change to the engine calibration at the same time given the same conditions. As these hypotheticals illustrate, deploying remote sensing and PEMS together can give effect to a superior testing program.

The following section summarizes a range of applications to which remote sensing specifically is well suited.

REMOTE SENSING APPLICATIONS

Because remote sensing allows researchers and others to cost-effectively gather emission data from a range of vehicles, it can contribute to various air-quality related programs, policies, and decisions. Below are nine broad categories of possible applications, some already in use.

Identification of individual high or low emitters. Remote sensing can be used to identify vehicles which in all probability have either a defective emissions control system or one that has been tampered with. Similarly, remote sensing can identify vehicles in which, in all probability, the emissions control system is functioning properly and fully. This capability could be used for a number of purposes, such as supporting and improving the accuracy and coverage of existing periodic technical inspection (PTI) programs, supporting roadside inspection programs, or supporting a "clean screen" program that lets drivers skip a periodic tailpipe emissions recertification test by verifying that their vehicle emissions are within a limit range.

Improve emissions and air quality models. Remote sensing can be used to generate real-world emissions factors at many levels of granularity. Depending on data availability, emissions factors may be generated for different vehicle groupings, such as: an overall average fleet, vehicle type (e.g., light-duty or heavy-duty), fuel type (e.g., gasoline or diesel), emissions standard (e.g., Euro 5 or Euro 6), manufacturer (e.g., Volkswagen or Renault), vehicle family (all vehicles with the same engine), or vehicle model. Real-world emissions factors could be used as input into various emissions models, air-quality forecast tools, or traffic models and would allow for a significant improvement in the accuracy of the outputs of such models.

Steer new policies. Local, regional, national, and European Union–level authorities are working to develop or improve policies that could be better informed with data obtained from remote sensing. For example, cities considering implementation of a low emissions zone or vehicle ban could utilize the data to predict the effectiveness of different policy iterations. Similarly, governments considering a vehicle scrappage and replacement program could identify the highest emitting vehicle targets, for maximum impact. Policymakers developing emissions regulations for new vehicles can use real-world data to identify limitations or defects in existing regulations.

Track policy effectiveness. Remote sensing data can help determine whether policies are producing their intended effects—e.g., whether a city's congestion/toxicity charging plan has resulted in a measurable decrease in pollution.

Track technology effectiveness. A number of new technologies could potentially have significant impact on real-world emissions. These include new emissions-control technologies (e.g., SCR-catalysed diesel particulate filters, gasoline particulate filters), new powertrains (hybrids, plug-in hybrids), new fuels (natural gas). And the effectiveness of existing technology can change over time, with use. Remote sensing data can be used to track the real-world effectiveness of technologies and how they change over time.

Screen the fleet. Market surveillance—identifying vehicle models or families that may not be complying with vehicle emissions standards—is a part of compliance and enforcement efforts. Remote sensing can be used to effectively screen the entire fleet and identify vehicle models with a high probability of a compliance issue (such as a defeat device, a product defect, or durability problems) that should be further evaluated with more extensive testing using PEMS or other in-depth testing techniques.

Monitor a single fleet. Remote sensing can be used by public or private fleet owners to track the "health" of their fleet. A fleet owner could, for example, set up a remote-sensing system to sample vehicle exhaust over many days, weeks, or months, and use the data to identify high emitters that should be repaired or replaced.

Understand the impact of specific driving conditions. Driving conditions such as vehicle speed, ambient temperature, altitude, and road grade affect real-world emissions. Some cities or regions may have specific driving conditions—for example, steeper grades, more extreme temperatures, or higher altitude—that cause the emissions profile there to differ from the average. Remote sensing can be used to identify how specific driving conditions impact emissions.

Inform purchasing decisions. Information on the real-world emissions of a particular make and model of vehicle can influence purchasing decisions both small (at the level of an individual consumer) and large (e.g., municipal bus fleets). Remote sensing can provide that type of information.

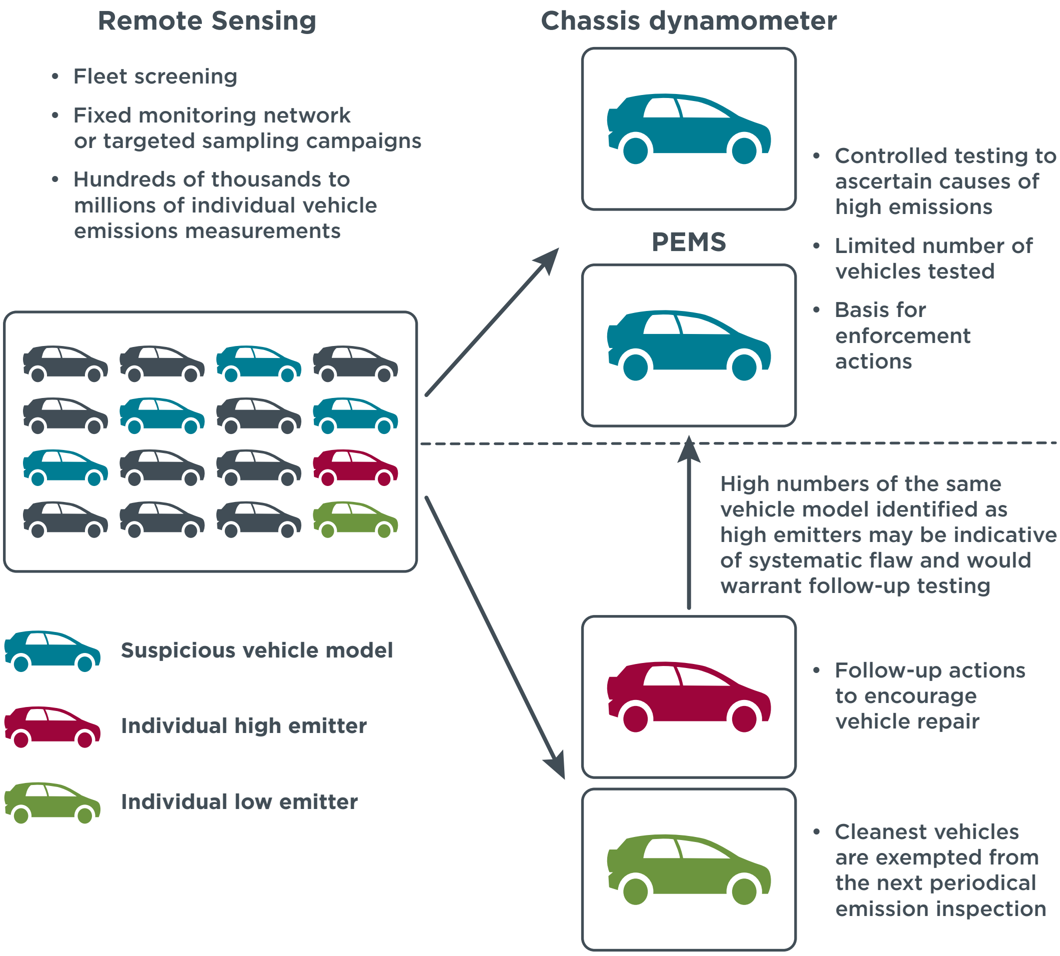

Figure 2. Conceptual diagram showing possible applications of vehicle remote sensing in an enhanced vehicle emission control program.