REMOTE SENSING MONITORING OF ON-ROAD VEHICLES

A READER

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Maps in this report are indicative and not to scale.

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Remote Sensing Monitoring of on-road vehicles

As cities are showing interest in implementation of remote sensing monitoring of on-road vehicles, there is a lot of curiosity about the nature and scope of this programme. There are several questions related it's design, technology for monitoring, measurement methods and data analytics, comparison with other measurement techniques like the current idling testing under pollution under control certification programme or lab based certification testing, and several aspects of its operations and compliance procedures.

While planning and designing an RSD program several elements will have to be addressed for implementation. Considerable learning has come from the global programmes as well as the local pilots conducted for Delhi including the 2019 pilot study of International Centre for Automotive Technology (ICAT). Extensive documentation of the global programmes have been carried out by the International Council on Clean Transportation (ICCT) under the TRUE initiative.

To demystify RSD, a rapid and an updated reader is adapted from the more detailed primer that was developed by the Centre for Science and Environment along with Ebyt Technologies Pvt. Ltd in 2022. Here are some basic facts to answer some of the frequently asked questions (FAQ).

1. WHAT IS RSD?

Simply put, remote sensing is a light source and a detector that is placed on the side of the road or at a height to transmit a laser beam to measure exhaust emissions remotely via spectroscopy as vehicles pass by and cross the light path. This can measure exhaust plume, and detect a range of pollutants including opacity, nitric oxide, carbon monoxide, hydrocarbons, and carbon monoxide in 0.5 seconds in the exhaust plumes of vehicles. This allows emissions measurements of large number of vehicles when they are being driven on the road and thus, do not require physical tests.

This can record emission rates from thousands of individual vehicles along with speed and acceleration across all driving conditions daily. This can test several vehicles per hour and within an interval of one second. A camera captures the image of the vehicle's number plate which, if connected with a vehicle registration database, can identify the make, model, certified emission standard, fuel type, rated power and other details. This system can screen large number of vehicles in a day.

2. HOW RSD HELPS TO IMPROVE EMISSIONS MONITORING?

The RSD programme helps to:

i) Identify high emitting vehicles that are the worst polluters on road that can be identified for proper checks and repair. This does not require physical testing like PUC.
ii) This allows clean screening of vehicles so that low emitting vehicles do not have to unnecessarily go for physical emissions inspection tests andavoid adding to the cost of inspection;
iii) characterize the emissions profile of the on-road fleet that can help to evaluate the established inspection and maintenance programs and also provide feedback on the technology performance; Increasingly, the focus is shifting towards generating data in the real world to improve technology performance of the vehicles.
iv) Use this monitoring system to regulate and restrict movement of polluting vehiclesin low emissions zones earmarked in cities.

3. WHAT DOES MEASURING EMISSIONS WITH REMOTE SENSING DEVICE MEAN?

Remote sensing data is generated as the vehicles are being driven on the road. In the most commonly used method, the target vehicle passes through the stationary exhaust sampling location which houses the emission analyzer. The sampler captures the target vehicle exhaust plume and measure the concentration of pollutants.

The advantages of using remote sensing data are several, including:

- Emission measurement from vehicle is unscheduled and no makeup of emission data is possible from vehicle owners.
- If measured properly, remote sensing data truly represent emission level from sample of vehicle in each program area.
- Remote sensing measurement can be implemented at fraction of cost as compared to vehicle inspection and maintenance programs.

- Vehicle emissions can be tested in wide range of driving conditions which isnot possible through other means of emission testing.
- Vehicles that often cannot be tested due to vehicle size on dynamometers can be tested using remote sensing equipment.
- The on-road data can evaluate the extent to which owners are maintaining their vehicles prior to emission testing.

4. HOW ARE LOCATIONS FOR RSD MONITORING SELECTED?

There are important criteria that need to be considered before finalizing locations for the installation of remote sensing devices. The location of remote sensing site witnesses a range of driving conditions that in turn effect the vehicle emission rates as a function of engine load. Within the same site the driving conditions vary, causing different emission measurements from remote sensing devices. Therefore, even single sites usually cover a wide range of engine loads, so that the average emission rate is based on a broad operating window. It is recommended to measure at different sites that covers wide range of driving conditions and a broader cross section of the fleet so that representative data can be captured.

General considerations

- The site should be selected based on objective of the study. Any site selected should have sufficient space to mount the equipment and allow safe setup and of instruments.
- Installation of remote sensing equipment should not disturb the ongoing traffic nor there should this interfere with the other street activities and pedestrian movement.
- If the objective of the study is to correlate the idle emission with remote sensing device, then sufficient space needs to be allocated for stopping suspected vehicles (flag by RSD) and check their idle emissions.
- Measured concentration from remote sensing device should be ascribed to individual vehicles. This is possible only when vehicles ply in clearly separable way without corrupting the exhaust plume of other vehicles. With the top-down configuration of the EDAR instrument, emissions from traffic on multi-lane roadways can also be measured.
- The site should be safe for the drivers, operators, and remote sensing devices.
- Single lane traffic (or multi-lane that could be directed to single lane) with enough shoulder space to install the device is preferred if crossroad setup configuration is used. However, if overhead setup configuration is used then there should be enough space to mount the pole on which device can be installed.

- The optical path length from source and detector should be no longer than 13 m to avoid decreased sensitivity and increased background noise for non-dispersive IR and UV techniques.
- To get good fleet characterization, a site where high vehicle turnover is witnessed should be chosen. From such sites large data can be collected from short amount of time.
- RSD sites should be chosen where vehicles experience engine load, ensuring exhaust gases contain combustion products. Ideal locations include spots with positive acceleration, mild road gradients, or where vehicles accelerate onto a motorway, uphill, or from traffic stops. Vehicle Specific Power (VSP), calculated using speed, acceleration, road grade, and aerodynamic drag, is key to assessing engine load. High VSP values indicate higher emissions, while readings below -5 kW/t are considered invalid for passenger vehicles, as fuel injection is disabled at that threshold.
- Site should be chosen such that maximum valid records can be collected without compromising geographic coverage and data quality.
- Remote sensing coverage area should be such that emission measurement distribution should roughly match the vehicle population else the data collected would be skewed towards one vehicle class or one fuel type and does not represent the true fleet composition in a geographical area.
- As RSD measure instantaneous emissions, one RSD measurement of a vehicle often time does not give true picture of vehicle performance. Hence any RSD coverage should allow for multiple observations of vehicles when sites are repeated. If there are multiple observations of the same vehicle, then average emissions will be more accurate than a single sighting.
- RSD data should be collected in different seasons of the year, capturing data from wide range of ambient temperatures.

Selection of RSD monitoring is decided by the measurement objectives

- RSD cannot distinguish between emissions from a cold engine to hot engine. A good choice for RSD location would be to measure cold start vehicle emissions from long-term parking lots and highway exits for hot engine emissions. RSD should be located at place where there is a low probability of vehicle cold start to exclude false detection of high emitter particularly for gasoline cars
- Urban sites can be chosen if the objective of the study is to compare the emission rates during urban and moderate driving conditions like conditions encountered in vehicle homologation tests. When conducting research, such as on the emission rates during aggressive driving that simulate the off-cycle emission rates, then the above restrictions do not necessarily apply.

- Additional selection criteria should be taken into consideration for different study purposes. Off-cycle high-load or high emission events should be avoided as well, e.g. steep hills. For emission factors and emission model development purposes, several sites covering different driving conditions and vehicle types are needed.
- If the objective of the study is to compare the effectiveness of vehicle I/M (Inspection and Maintenance) program, then RSD should be installed at both I/M area and out of I/M area. Comparison between the two will help in ensuring that I/M centers are effective in checking and controlling the health of overall vehicle fleet.
- The RSD program objective is an important criteria for selecting a site. If the objective is to measure vehicle emissions from class of vehicle, then sites where those vehicles ply should be chosen. A congested city market is full of 2/3 wheelers. Such place is ideal to study vehicle emissions of 2/3 wheelers. Proper vehicle funneling may be required to force the vehicles through RSD setup. However, necessary permissions may be required from local authorities to set up an RSD device.

How are sites selected for pilot study? On-road RSD monitoring was carried out at sites that meet criteria such as: (a) Vehicle emissions will be measured during rapid acceleration phase; (b) Vehicles will pass through a single lane for them to be covered efficiently by emission analyzer; (c) Installation of RSD does not disturb the running traffic or obstruct other activities on road including pedestrian movement.

Sampling plan development and securement of permits and approvals

Develop sampling plan and select sites for measurements. Obtain necessary permits and approvals to conduct sampling. The sampling plan should include details of selected measurement location(s), sampling schedule, expected daily sample size, expected number of measurement days, and other details relevant to testing strategy and preparation. The format for reporting data will also be established.

Need indication of the total footprint of the selected remote sensing instrument package and description of any modifications to existing roadways that would be required for the installation of sampling equipment. Other relevant details, such as power requirements, should also be provided. Any sampling equipment constraints that would serve to limit the scope of suitable measurement locations (e.g. need for single lane roadway) or instrument deployment and data collection (e.g. ambient weather conditions—temperature, rain, high winds, etc.) should be noted in the proposal.

This requires approval from different departments. Each departments has different protocols when it comes to permitting such activities. VAHAN database access is required to retrieve vehicle information from registration plate captured by RSD camera during on road data collection with remote sensing device. The information from VAHAN database needs to be merged with emission data collected during on road testing for final analysis. In India, vehicle information is hosted in VAHAN database, which is owned by NIC (National Informatics Centre).

5. TECHNOLOGY PATHWAYS FOR REMOTE SENSING MONITORING

Remote sensing devices (RSDs) screen on-road vehicles, separating high and low emitters for targeted inspection using infrared (IR) and ultraviolet (UV) beams to measure pollutants like CO, HC, NOx, and PM. Advanced RSDs also detect gases like NH_3, SO_2, and specific hydrocarbons. Integrated systems measure vehicle speed, acceleration, and capture license plate images, enabling quick, contactless analysis within seconds. Despite challenges from environmental factors, global adoption of RSDs is increasing, with advancements like laser-based sampling enhancing accuracy. While limited in India, growing interest suggests expanding applications in emission monitoring

Remote sensing devices (RSDs) are being used to screen on-road vehicle fleet, separating low and high emitters for targeted inspection. RSD uses infrared (IR) and ultraviolet (UV) light beams across roadways to measure pollutants like carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). IR for carbon monoxide and hydrocarbons, and UV for nitrogen oxide and particulate matter.

Advanced instruments (FEAT) can also measure ammonia (NH_3), sulfur dioxide (SO_2), and specific hydrocarbons like methane (CH_4). In addition, RSDs measure the speed and acceleration of the passing vehicle to understand the emissions measured and captures an image of the license plate to identify the vehicle. Speed and acceleration provide a measure for the vehicle's engine load, conventionally expressed as vehicle specific power (VSP). These systems require no physical contact with vehicles and offer quick, convenient testing by analyzing light absorption (spectroscopy).

RSDs operate through three integrated systems: (1) a speed and acceleration detector, (2) a license plate camera, and (3) an emissions analyzer. Vehicles passing through the IR/UV beams trigger these systems, enabling precise measurement in less than a second. The resulting data, including vehicle speed, acceleration, and pollutant levels, is captured for real-time analysis. RSDs can detect fine particulate emissions from both older diesel vehicles and modern diesel engines with controlled devices.

Despite their effectiveness, RSDs face challenges from environmental factors like rain and fog, which can impact visibility and data accuracy. Globally, remote sensing technology is evolving, with advancements in both open-path and extractive methods. Open-path systems utilize light sources and detectors placed along or above roadways to measure exhaust plumes, while extractive systems capture and analyze portions of the exhaust for pollutant concentrations. Countries like the UK, France, Germany, and the US are increasingly adopting these technologies for urban emission monitoring.

In India, the adoption of RSDs remains limited, although interest is growing. Improved systems with features like laser-based sampling are emerging, offering greater speed and accuracy in pollutant detection. As these technologies develop, their role in global emissions control will expand, driven by innovations and new applications across different vehicle types and environments.

6. WHAT IS THE DIFFERENCE BETWEEN PORTABLE EMISSIONS MONITORS (PEMS) AND REMOTE SENSING DEVICES (RSD)?

Currently, remote sensing and portable emissions measurement systems (PEMS) share the common objective of measuring on-road emissions of vehicles. Therefore, there is a curiosity about how to relate the two approaches.

The two techniques differ mainly on how their emissions are measured. Remote sensing can measure emissions from thousands of vehicles per day as they pass by. A snapshot of the exhaust plume content is collected from each passing vehicle, equivalent to about one second's worth of emissions data for a single operating condition. Portable emissions measurement system testing (i.e. PEMS) uses sensors and analytical equipment mounted on a selected vehicle to directly measure the second-by-second emission rate of a vehicle as it is being driven on the road during a given trip, driving style and weather conditions.

A study (Sjödin et al., 2018) compared NOx emissions from Euro 5 and Euro 6 cars using PEMS data and the CONOx remote sensing database, on a vehicle make, brand, and model. PEMS data was derived from the government sources in Belgium, Germany, France, the UK, and the Netherlands (105 Euro 5 models and 93 Euro 6 models) and from organizations like TNO, Emissions Analytics, and ADAC (124 Euro 5 models and 220 Euro 6 models). The results highlight the correlation between NOx emissions from remote sensing measurements and PEMS tests for Euro 5 models.

The main conclusion from the study was that there is good agreement between PEMS and remote sensing data. This study captures and compares the emissions from PEMS and remote sensing data with respect to per kg of fuel burned.

Other studies, including those by Birmingham and Leeds Universities (Ropkins et al., 2017), found high agreement (R^2 values up to 0.97) between EDAR and PEMS measurements under real-world conditions.

7. HOW IS RSD EQUIPMENT SET UP?

The instrument consists of three units which needs to be installed. The light and mirror need to be aligned with each other so that light beam emitted by source device should be collected by the mirror module. The height of the source module needs to be adjusted so that light beam pierces the exhaust beam. The speed measurement bar needs to have its signal at the height of the wheels. And finally, the camera must be adjusted to capture the back number plate well. Depending on the remote sensing device, the equipment needs to be calibrated at prespecified frequency which depends on equipment specification to prevent equipment drift.

The calibration should be done every hour during operation until the stability of the individual system is quantified and characterized using statistical process control methods. Once control charts have been established, the calibration frequency may be reduced appropriately. Several puffs of gas designed to simulate all measured components of the exhaust are released from a cylinder containing certified amounts of NO, CO, and propane into the optical beam path. The ratio readings from the instrument are compared to those certified by the cylinder manufacturer. In this way the system compares the pollutant ratios in a known standard gas cylinder and those measured in the vehicle exhaust. The gases used for the second calibration shall by certified to +/-2% of a known standard and be in the following ranges:

- CO 1–9 per cent

- HC as C3 300–4,100 ppm
- NO 15,00–3,600 ppm
- 5–14 per cent (with the balance oxygen free nitrogen)

When the setup and calibrations are completed, emissions from passing vehicles are measured.

8. HOW DOES RSD EQUIPMENT PROCUREMENT NEED TO FOCUS ON DATA SAMPLING AND PROCESSING?

Indian cities will soon be procuring new remote sensing devices. Such procurement will require detailed RFPs and proposals for tendering and procurement. It is therefore important to understand some of the performance indicators that other governments and agencies globally are focusing on. Some of these have been reviewed to identify key technical points regarding remote sensing equipment procurement to guide action in Indian cities. RFPs and proposals need to focus on the following salient features. These can be further expanded during the actual procurement phase.

Data collection

Describe in detail how they will sample exhaust emissions from all variations of vehicle exhaust configurations, and for carrying out measurements of exhaust air pollutant emissions and operating conditions of vehicles passing the sampling location(s) and for recording the number plates of sampled vehicles. At a minimum, the remote sensing instrument should be capable of measuring the concentrations of the following species in the exhaust plumes of individual vehicles:

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Nitric oxide (NO)
- Nitrogen dioxide (NO_2)
- Hydrocarbons (HC)
- Opacity and/ or particulate matter (PM)
- Optional: Ammonia (NH_3)

The achievable measurement precision for each of these species should be detailed in the proposal, as well as any additional pollutant measurement capabilities. Also include as part of the instrument package equipment for the measurement of the operating conditions of vehicles undergoing emissions measurements, GPS location of the site, lane direction, and road grade.

Specifically, measure the speed and acceleration of passing vehicles at the time of emissions measurement. Ambient weather conditions (e.g. temperature, relative humidity, wind speed and direction) should also be measured concurrently with emissions measurements. Finally, contractors should record the number plate of each sampled vehicle.

The contractor is responsible for the proper set-up and operation of all equipment and for conducting appropriate instrument calibrations to ensure data quality. Detailed calibration records shall be provided in the final report.

During the sampling campaign the contractor should provide regular status updates detailing the progress of the campaign to date and any deviations from the original sampling plan. The frequency of status updates will be agreed upon during the planning phase of the project.

Data processing and number plate matching

Vehicle remote sensing project requires:

i) Data analysis, processing and reporting—Data processing, data matching, statistical analysis and reporting
ii) Data collection—Cut point/ threshold limit learning and pool over inspections
iii) Planning and operation—Project planning, site selection and site approval and linking local authorities

Following the data collection phase of the project, the contractor will be responsible for processing collected emissions and operational data and reporting in a format agreed upon during Task 1. Criteria for establishing the validity of individual emissions measurement records should be detailed in the final report.

Provide data in a format agreed upon during the planning stage of the project. A detailed list of desired data fields to be included. Provide records for individual vehicles grouped into the following three categories:

- Vehicles with valid emissions measurements matched to vehicle registry
- Vehicles with valid emissions measurements not matched to vehicle registry
- Vehicles with invalid emissions measurements matched to vehicle registry

Criteria for establishing the validity of individual emissions measurement records should be detailed in the final report. The contractor will be responsible for matching vehicle technical information provided by the authority with emissions records.

Data reporting

The contractor/operator will deliver a full report, with emphasis placed on the data collection and processing phases of the project. The report should contain at least the following items:

- Detailed sampling plan
- Description of measurement location(s)
- Description of sampling equipment
- Instrument calibration records
- Summary of data collection campaign
- Details of data processing and validation approach

Detailed analysis of the collected data, e.g., data aggregation by vehicle type, model year, emission control level, operating mode, etc., is outside the scope of this project. The contractor is welcome to perform and report such analyses, though the budget for these steps should not come at the expense of other project activities of greater importance, e.g. data collection.

Data reporting fields

The following fields should be included in the final vehicle emissions database provided by the contractor:

- Vehicle passage date and time
- Vehicle speed [mph]
- Vehicle acceleration [mph/s]
- Vehicle specific power [kW/ton]
- Concentration [%]
- Concentration CO [ppm]
- Concentration NO [ppm]
- Concentration NO_2 [ppm]
- Concentration HC [ppm as propane or other reference hydrocarbon]
- Opacity (or concentration PM)
- Ratio CO/
- Ratio NO/
- Ratio NO2/
- Ratio HC/
- Ratio PM/
- Emission rate CO [g/kg fuel]
- Emission rate NO [g/kg fuel]
- Emission rate NO_2 [g/kg fuel]
- Emission rate NOx [g/kg fuel as NO_2]
- Emission rate HC [g/kg fuel]
- Ambient temperature [°F]
- Relative humidity [%]
- Barometric pressure [mbar]

- Wind speed [m/s]
- Wind direction [°]
- Precipitation
- Road grade (%)

Desired vehicle technical information is included below:
- Plate number
- Vehicle identification number
- Vehicle type/category
- Fuel type
- Vehicle make

Government will reserve the right to make minor modifications to the Scope of Services for the Contract resulting from this RFP. Such modifications may include but are not limited to, assignment to the Contractor of programmatic tasks not previously specified but within general parameters of the RFP. Payment for completion of these tasks will be negotiated by the parties.

The project evaluation involves cleaning and validating remote sensing data, primarily focused on transcribing number plates. Automated OCR software, integrated with the RSD, scans captured images to extract vehicle plate numbers. These are matched with vehicle details from the central registry. The emission data, along with speed and acceleration metrics, is then combined with the registry information for analysis.

Data analysis: The last step in remote sensing is data analysis. Data analysis is broken into various categories which depend on type of data extracted from vehicle registry.

Evaluate data integrity: The data collected from remote sensing should meet minimum standards of quality to be used in analyses. Following criterion must be applied to remove suspect test records:
- Measurements with inadequate signal strengths.
- Measurements with too much uncertainty.
- Measurements from sites where data is suspected of being compromised during any period of the data collection.
- Measurements from sites or sessions that appear to have unusually high or low average emissions levels.
- Analysis for high emitters should exclude measurements with Vehicle Specific

Power (VSP) less than 3kW/t and greater than 25 kW/t.

Other RFP elements include anticipated contract term; compliance with law; contract provisions and requirements; subcontractor compliance notice; and anticipated payment structure.

Technical proposal

a) Demonstrated quantity and quality of successful relevant experience
b) Project management process
c) Methodology
   i. Provide a detailed methodology
   ii. Describe the deliverables.
   iii. Provide a description of the remote sensing equipment that will be used for this project.
   iv. Provide a timeline for the development of the tasks.

Price proposal and project evaluation procedure and criteria

9. HOW IS FLEET AVERAGE EMISSION MEASUREMENT ESTIMATED?

RSD can be used to measure average fleet emissions. This measurement when collected over a period can be translated to what extent tightened emission limits led to emission reduction in on road emission. Short term average emissions from RSD inform about the average CO, HC, NOx emissions of the fleet. However, with comparable measurements over several years can be used to analyse the development of average fleet emissions over time. All this information is very useful for a comparison with the average emission factors as well as fleet composition assumed in an emission inventory or an emission model.

The change of average emissions of the rolling fleet depends on the unit emissions of each vehicle class on the fleet turnover, i.e., the share of new vehicles with progressively lower unit emissions added and of old vehicles with higher unit emissions retired, and the respective mileage of the different vehicles – as per the ICCT report on remote sensing of motor vehicle exhaust emissions. RSD can help to corelate data with age, vintage and fuel types.

10. HOW TO CROSS-CHECK ON I/M PERFORMANCE?

A remote sensing program is being used as an on-road complement to existing station-based periodic emissions inspection programs. Vehicles must periodically (e.g., annually) report for an emissions inspection at specialized centres which are setup under Inspection & Certification (I&C) programs.

As vehicles ply on the roads during their inspection cycle, RSDs installed at different places characterize the on-road emissions distribution of the motor vehicle fleet and efficiently distinguish between the highest and the lowest emitters.

The lowest emitting vehicles can be notified stating that they are certified as compliant by RSD and may complete their I&C requirement including paying the applicable fee online without physical tests in I&C stations.

At any time during the inspection cycle, the highest emitters can be notified stating that they need to report (e.g., within 30 days) for re-inspection and re-certification. If highest emitters are not repaired to be compliant, they need to be retired and replaced. This approach helps to focus the I&C tests on the most polluting vehicles and this leads to emissions reduction and accelerated fleet turnover.

Finally, a proper low-emitter exemption program (i.e. clean screen) fees can fund all remote sensing operations. While this will reduce the cost to the state, it will also substantially improve the convenience and effectiveness of the I&C program. Thus, emission monitoring through remote sensing devices is used for emission inspection convenience and effectiveness.

11. MORE NUANCED FLEET CHARACTERISATION IS POSSIBLE

Remote sensing data can be analyzed in greater details depending on sample size and vehicle information available from vehicle registry (Borken and Dallmann 2018). Fleet characterisation can be broken down into further details that can answer following questions:

- How diesel cars emissions compared to petrol cars?
- Within same fuel type what proportion of cars comply with different emission standards?
- For same fuel type and emission standard, how are the emissions from two manufacturers compare?

- For same manufacturer how are different models, which comply with same emission standards and having same fuel type, compare?

A map of real-world emissions can be developed by monitoring real-driving emissions in different locations of the city or area. Because of this, portable RSDs can be deployed in different roads and streets every few days. Emissions can be analyzed based on different parameters such as:

- Urban parameters: city district, specific site, road slope, road type, traffic intensity, etc.
- Vehicle parameters: fuel type, vehicle type, vehicle age, Euro standard, weight, brand, model, etc.
- Traffic parameters: traffic intensity, time slot of the day, nearby traffic incidents, etc.

12. HOW TO USE REMOTE SENSING DATA TO EVALUATE THE EFFECTIVENESS OF A PROGRAM?

Remote sensing data can be used in several ways to evaluate the effectiveness of an I&C program:

- Remote sensing measurement of vehicles happen at different times and quite randomly between scheduled I&C tests. Therefore, remote sensing data can be used to assess how quickly effectiveness of repair diminishes over time and extent of repair just prior to the I&C tests, as well as track changes in fleet emissions due to changes in test procedures.
- Remote sensing programs measure almost every vehicle that drive past the instrument on the road, regardless of whether it is participating in the I&C program. Remote sensing data therefore can be used to estimate the number and emissions of vehicles legally exempted from, or illegally avoiding, the I&C program, as well as estimating their emissions. In addition, remote sensing data can identify individual vehicles that never complete the current I&C cycle, or that do not report for testing in a subsequent test cycle but are still being driven in the I/M area.

Evaluate sample distribution: Depending on type of information retrieved from the vehicle registry, vehicles can be segregated into different classes based on:

- total number of registered vehicles.
- total number of registered light-duty gasoline vehicles, trucks, etc.
- total number of registered heavy-duty diesel vehicles, trucks; etc.
- total number of registered motorcycles/scooters etc.

Compare vehicle registration data by class with aggregate fleet composition to ensure representative sampling. Investigate discrepancies, and recommend corrective actions to improve site selection or remote sensing methods for more accurate results.

13. HOW DO WE UNDERSTAND THE MEASUREMENT UNITS (CONVERSION OF POLLUTANT FROM GM/KG TO GM/KM)?

Emission rates measured by remote sensing are instantaneous, usually under positive acceleration, and without idling. Their unit is typically gram (or mole) pollutant emitted per gram (or mole) emitted. Emission factors from type approval or RDE tests are typically cycle or trip averages, and thus include constant speeds, accelerations, decelerations and idling, and possibly also cold start extra emissions. The regulatory limits for pollutants are defined as the mass of pollutant per unit of distance travelled (e.g., grams [g] per kilometre [km]) for light-duty vehicles and per unit of output of mechanical energy (e.g., g/kilowatt hour) for heavy-duty vehicles. Obtaining the emissions in above units requires measuring the pollutant mass emission rate. A general formula for the pollutant mass emission rate is described below. It is proportional to the pollutant concentration and to the total exhaust mass flow.

Pollutant mass rate = C × pollutant tailpipe concentration × exhaust mass flow

In the equation, C is the ratio between the densities of the pollutant and the total exhaust, and it mainly depends on the pollutant studied and the fuel used.

Even though mass emissions are a function of tailpipe pollutant concentrations, as shown in the equation above, the main risk with using pollutant concentrations for assessing vehicle pollutant emission levels is the lack of information about the mass flow of the pollutants. Vehicles equipped with diesel engines tend to exhibit higher exhaust mass flow rates than most vehicles with gasoline engines when tested in similar conditions (e.g., same power demand). This is due to their need to run with a large excess of air. In other words, even when there are similar tailpipe concentrations for gasoline and diesel vehicles, the diesel vehicles emit more mass emissions. This means that the crucial link for enabling comparisons between emission rates as measured by remote sensing with those measured in conventional emission tests is the fuel consumption in mass or volume unit per distance driven. The ICCT has carried out extensive study on this aspect.

14. HOW TO RELATE RSD WITH TRAFFIC FLOW FACTORS?

The number of vehicles passing from remote sensing equipment at each site should be compared with traffic flow information in last 24-hours. Based on traffic information from all sites, statistical correlation should be done to check if 24-hour traffic counts and measured traffic flows from remote sensing equipment match. If such correlation exists for either all sites or specific types of sites, then criteria should be developed to identify remote sensing sites that maximize fleet coverage in future remote sensing programs. If statistically significant variations exist between different sites, then factors such as geographic, road type, traffic flow direction, etc. needs to be identified that contributed to the differences.

15. HOW TO ENSURE OVERALL FLEET COVERAGE?

The observed fleet coverage in a remote sensing program area can be calculated by getting information on vehicle fleet composition based on parameters such as vehicle class, vehicle model year from vehicle registry. This data can be compared with measured data from remote sensing devices. Percentage coverage of vehicles can be calculated by taking the ratio of vehicles observed in program area against the composition of vehicles, based on above parameters, in same program area. If the ratio is low, then reasons for low coverage can be investigated and effective measures can be taken to improve vehicle coverage for current and future RSD programs.

16. HOW TO UNDERSTAND BREAKDOWN OF EMISSIONS?

Emissions by vehicle type and model year from observations of vehicles in the program area can be grouped. For each group, data will be sorted by emission level and presented in appropriate increments (quartiles, deciles, etc.) for the overall fleet. Results for older vehicles will be aggregated into model year ranges if there is an insufficient sample for each model year. As an example, classification of light duty petrol vehicles can be based on the predominant vehicle technology approaches:

- pre-catalytic converter
- catalytic converter/carburetted
- closed loop/carburetted
- closed loop/fuel injected
- OBD I/OBDII

Moreover, from speed/acceleration and site grade data vehicle specific power can be calculated. Measurements can be classified according to vehicle specific power, and average emissions can be plotted. Measurements with a VSP value that exceeds the range covered by certain certification test procedures will be excluded because they may legitimately be operating with an enriched fuel/ air mixture.

17. HOW DOES RSD HELP TO IDENTIFY HIGH EMITTERS?

As mentioned earlier, on-road remote sensing has been used to filter out vehicles with highest absolute emissions in the fleet. These are mostly older vehicles or vehicles with dysfunctional after-treatment.

18. HOW CAN EMISSIONS CUT POINT BE DEFINED?

Data from the initial part of remote sensing measurement should be used to define emission cut points for different vehicle classes (light-duty, heavy-duty, 2-wheelers, etc.). The definition of emission cut point is important to identify high and gross emitters. If there is sufficient data the cut points can be further segregated not only based on vehicle class but also on fuel type within the same vehicle class (light-duty petrol, light-duty diesel, heavy-duty diesel, etc.). For cut point definition, usually 5 percent percentile rule is followed, implying that the top 5 percent vehicle causes maximum emission.

Remote sensing technology uses a snapshot measurement to determine if a passing vehicle is clean or high emitting. However, the transient emissions of vehicles are highly variable. It is important to recognize that a vehicle with high instantaneous emissions does not necessarily mean that it is a permanent high emitter. Clean vehicles may have high emissions occasionally, such as during load change conditions. To ensure the confidence of high-emitter determination by remote sensing, a key procedure is that the cut points should be safely above the emission levels of clean vehicles while still capturing as many high-emitting vehicles as possible.

Therefore, the remote sensing cut-points are defined as the highest instantaneous emission levels of vehicles that could still pass the regulatory emission test. In practical implementation of remote sensing enforcement program, other procedures to ensure the confidence of high-emitters determination include:

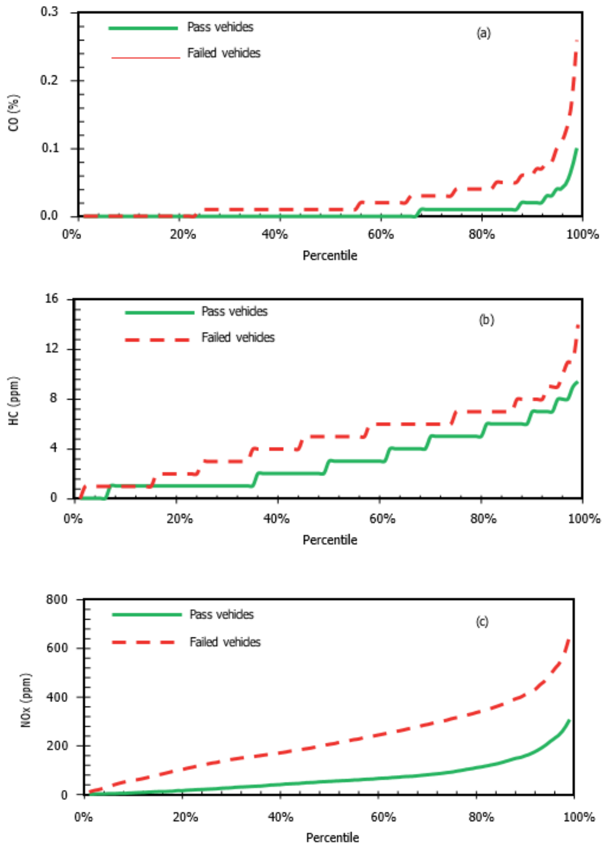
1) using remote sensing readings only within the speed and acceleration ranges of the regulatory emission cycle to avoid off-cycle emissions; and 2) using two

units of remote sensing systems with one second distance in between, and both measurements must be above the cut points to classify vehicle as high emitter.

Cut points in remote sensing are expressed as NO/ ratios (ppm/%)—the key parameter measured. NO concentrations are estimated based on the assumption that gasoline and LPG engines run stoichiometrically, but this doesn't apply to diesel engines, often leading to false detections of high emitters.

To determine cut points, a large sample of vehicles from the same class, fuel type, and emission standard should be tested. The sample should include various model years and a mix of vehicles that both pass and fail regulatory tests. Emission results are plotted in percentiles for pollutants like CO, HC, and NOx. A good cut point is the 99th percentile for vehicles that pass, minimizing misclassification as high emitters. Diesel vehicles, with lower CO and HC but higher NOx, require careful threshold selection due to close overlap between pass and fail curves, increasing the risk of false positives.

Graph: Illustrative case: CO (a), HC (b) and NOx (c) emission percentiles of pass and failed vehicles



Source: Y. Huang, B. Organ, J.L. Zhou, N.C. Surawski, Y.S. Yam, E.F.C. Chan - Characterisation of diesel vehicle emissions and determination of remote sensing cutpoints for diesel high-emitters. Environmental Pollution 2019; 252: 31-38. DOI: https://doi.org/10.1016/j.envpol.2019.04.130

19. WHAT IS CLEAN SCREENING OF VEHICLES?

Clean screening refers to the program where vehicles are exempted from inspection after being detected several times in remote sensing measurement as having very low emissions. The program offers convenience to vehicle owners by exempting them to visit inspection centre when their vehicle is flagged clean by remote sensing device. In a way it is the opposite of the high-emitter screening discussed above. The "clean pass" limits are set quite low to guarantee clean operation also under different than measured driving conditions. All relevant pollutants need to be measured as there are no reliable correlations among them.

Other applications of remote sensing can be:

- RSD screening programs can amass very large databases of on-road emissions measurements. For example, the largest US clean screen programs gather millions of high-quality (i.e., valid) measurement annually. Such databases can be mined for numerous other beneficial applications of remote sensing data.
- Gross liquid (i.e., fuel) leak detection: Virginia issues advisory notices to gross liquid leakers.
- Remote sensing can be used to understand emission control device (i.e., catalyst) deterioration factors.
- Remote sensing data can be used for verification of on-board diagnostic systems. This helps to understand if the vehicle OBD systems are functional and serve their intended purpose.

20. HOW TO CORRELATE RSD MONITORING WITH PUC RESULTS IN INDIA?

As noted earlier, a separate Pollution Under Control (PUC) program is required for vehicles in India. The PUC program in most cities mandates an emissions test twice a year for every vehicle and requires that emissions do not exceed the norms. For petrol, CNG, and LPG vehicles, emissions are measured at low idling conditions, while for diesel-operated vehicles, a snap acceleration (a protocol that involves repeatedly snapping the throttle fully open to go from an idling engine to full power) or free acceleration test is used. PUC tests have evolved over time for different generation of mass emissions standards. PUC norms for BSIV and BSVI compliant vehicles have been tightened further.

There is considerable curiosity among transport regulators about the coexistence of remote sensing and PUC programs as enforcement measures. However, to understand the compatibility of PUC and RSD programs more data is needed to analyze statistically if there is significant correlation between the two. The limited data available so far shows that there could be weak correlation between PUC and RSD results to identify high emitters.

Under the Indian PUC programme, periodic physical checks of exhaust emissions from vehicles will continue to assess compliance with limits imposed on idling emissions. However, it is important to understand that the remote sensing programme will screen vehicles on the road with more dynamic driving conditions to identify gross or very high emitters.

It is possible that some vehicles may escape or even pass PUC tests and yet experience technical anomalies that may make them high emitters between two scheduled PUC tests. PUC test is no load test which has little relevance to classify vehicles as high or low emitters. Due to the limitations of PUC, remote emission measurement using RSD is a better method to measure real world emissions for effective action.

However, there is a need for a national guidance and rule to define how the two systems can coexist.

21. HOW MANY RSD DEVICES ARE NEEDED IN A CITY?

There is no clear benchmark for the number of monitors that a city needs to have. The size of the city, traffic volume and the level of ambition of the program will influence that decision.

For instance, a big city like Beijing with ambitious air pollution program has 30 remote sensors; a small city like Hong Kong has about 15 monitors – as of 2020-21. These sensors can be strategically and flexibly located in different parts of the city for rapid screening of vast section of traffic.

22. HOW MUCH WILL IT COST TO IMPLEMENT AN RSD PROGRAMME?

The primary factor governing the cost of any RSD program depends on program objective. If the program objective is to evaluate emissions from vehicles plying on highways, the cost of setup and manpower will be less as compared to measuring vehicle emissions on congested city roads. For setting up RSD instruments in city roads additional safety of manpower and equipment needs to be arranged, thus increasing program cost.

The cost of RSD program also depends on number of sites selected for monitoring vehicle emissions. Greater the number of sites, higher will be cost of the program.

The cost of the RSD program also depends on technology chosen for RSD device. Earlier estimates show that laser based device from HEAT is more expensive than IR/UV based device from OPUS. But a lot of this can change with localisation of production and economy of scale.

Ultimately, the ambition level of the remote sensing expectation will be determined by the cost of these instruments. This will need more scoping. However, the available data from different countries show that remote sensing devices may largely cost in the range of Rs 2.5–3+ crore in India. The overhead monitors and the attendant systems will cost more.

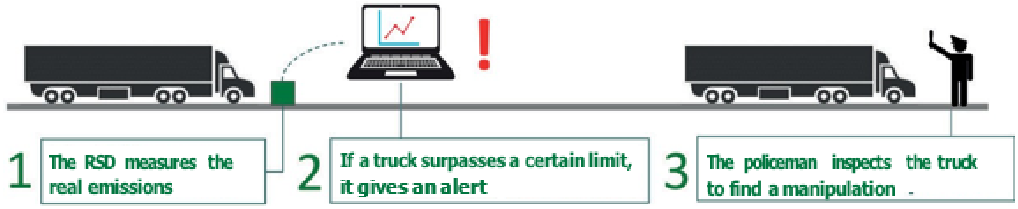
23. HOW CAN AN RSD PROGRAMME BE LEVERAGED FOR ENFORCEMENT AND PULL-OVER INSPECTION?

Based on the RSD monitoring the law enforcement agencies can stop and pull out the high emitters and send them for repair. Notices can be issued online, and the vehicles can be asked to go for repair and report back for tests.

However, as global programs show, remote sensing can also alert the local law enforcement agencies about the potential tempering of aftertreatment system in vehicles especially heavy-duty vehicles. To save operating cost many fleet operators usually disable the AdBlue injection system that is needed to control NOx emissions. This manipulation is done in different ways, some of them with the so-called “AdBlue killers” which are devices that can be purchased for a very low price and can be easily installed into driver’s cabin. The AdBlue killer makes the computer believe that it is injecting AdBlue when it is not. Finding and penalizing such drivers or fleet operators are required by enforcing agencies.

The only option to catch manipulation is to have real time emission measurement that can be performed by remote sensing device. This can improve the effectiveness of enforcement and prevent tampering (see Fig. 4: Real driving emission monitoring for heavy duty vehicle to catch AdBlue killers.)

Figure 4: Real driving emission monitoring for heavy duty vehicle to catch AdBlue killers



Source: https://www.opusrse.com/remote-sensing-applications/police-enforcement/

24. WHAT ARE THE OPERATIONAL LIMITATIONS OF THE REMOTE SENSING PROGRAMME?

RSD have various limitations in hardware. measurement accuracy, road type and configuration, vehicle traffic and speed, meteorological parameters, and tailpipe configuration.

There are various challenges during emission monitoring using remote sensing equipment:

- During unfavorable meteorological condition such as rain, fog etc., RSD camera may not capture the number plate data of vehicles. Also, less lighting and less visibility in night can impede camera capture of number plate data.
- The different orientations of tail pipe in heavy duty vehicles are one of major challenges to collect RSD data. Special arrangement may be needed for keeping camera on the way of upstream gas analyzer.
- Sometime vehicles registration details may not be available in central server (VAHAN database) for vehicles that have been tested. Such data may have to be discarded.
- One of the major challenges to getting convince people for getting their vehicle inspected during pull over inspection. Many of the vehicle owners may dispute during inspection.
- Public movement during on road measurement can result in data loss.
- RSD device is based on optics and mirrors, which play important role to maintaining alignment of light source to capture the plume. Due to dust and pollution, mirrors may have to be changed.
- Guard against system failures with frequent and mounting and dismounting of equipment.
- Dynamic cut-points need to be also challenged during screening programmed which is dependent on vehicle speed, acceleration, and load etc.

These issues need to be understood in greater detail.

Signal to noise (S/N) considerations: Remote sensing measurements would be very easy if all the emissions are measured directly behind the car exhaust tail pipe. In such a case light absorbed by pollutant would be large and S/N will cause any limitations. In fact, vehicle tailpipes are not in standardized configurations, vehicle engine sizes are not uniform, and there is very rapid turbulent dilution of the exhaust behind vehicles moving faster than about 5 mph. Thus, one has to make an engineering trade-off between a desire to measure emission from maximum vehicles and still have adequate S/N ratio so as not to detect incorrect emission values.

Remote sensing instrument builder's challenge is to build a system in which changes in IR and UV intensity due to exhaust dilution are accurately measured in all weather conditions beside a normal road at a measurement frequency of 100 Hz. Further the exhaust dilution, harder it becomes to capture the signal of adequate strength for accurate detection of pollutant gases. This bleak outlook is somewhat mitigated by the fact that the light source need only maintain a stable intensity for about two seconds for a complete measurement series and the fact that the data reduction process averages for 1/2 sec.

Weather: Measuring light intensity from remote sensing device over greater path length of light (distance between source and detector module) can be inhibited by bad weather which otherwise would not be a problem. Snowflakes and heavy rain add too much noise to measurement channels. Wet or very dusty roadways cause a plume of spray or dust behind vehicles moving above about 10 mph. These plumes also add noise to the system, and generally increase the data rejection rate to an unacceptable level.

Interference: The HC (hydrocarbons) wavelength suffers from some interference from gas phase, particulate phase and water also called steam plumes which forms from colder vehicles operating at low ambient temperatures. When steam plumes are so thick such that light from all wavelengths are absorbed or scattered too much for useful data to be acquired.

Optical alignment: If the instrument is not perfectly optically aligned, the voltages are likely to be very sensitive to equipment vibration. Since moving vehicles both shake the roadway and generate wind pulses, rigid instrument mounting is as important as perfect internal and external optical alignment. Software is written so that these noise sources generate invalid flags. Proper alignment at a well characterized RSD-site can yield 95 per cent valid RSD readings on passing vehicles.

25. IS THERE A CHALLENGE OF EMISSION VARIABILITY?

Emissions of motor vehicles are not constant from second to second or from day to day. Broken vehicles often seem to have a large random component to their emissions irrespective of what test is used to make the measurement. Some vehicle emission variability has known causes such as the initial operation of cold vehicles before the engine control system stabilizes and the catalyst begins operation, or when the vehicle is accelerated at full throttle. Both situations give rise to large CO and HC emissions from even well-maintained vehicles but can be minimized through careful site selection.

26. WHAT ARE THE OTHER LIMITATIONS?

- Remote sensing device works most accurately under slight acceleration, e.g., uphill roads; therefore, emissions during idle and deceleration are considered as invalid.
- Evaporative emissions do not correlate with carbon dioxide emitted from fuel combustion. While it is harder to locate the exact source of evaporative emissions, any lack of correlation with emissions points to a leakage that could warrant closer follow-up inspection of the individual vehicle.
- RSD collect the emission data for around 1 sec. This short span cannot be used to accurately characterize a vehicle's emission performance. However, with a large sample size, remote sensing can provide accurate results on fleet average emissions.
- Congested traffic limits the rate of measured vehicles.
- Estimation of tailpipe concentration for lean combustion engines, such as diesel engines, cannot be estimated accurately by open path systems, as the exhaust dilution rate is unknown. This may complicate the use of remote sensing to replace stationary emission inspection whose testing protocol usually define thresholds based on tailpipe concentration. Alternatively, these limits could be replaced by thresholds relative to fuel or .
- Access to vehicle registration information is required to identify the vehicle specifications from the license plate. This access is usually controlled by local authorities, which may have restrictions regarding data access. Even when access to vehicle information is granted, approval may be time-consuming and costly.
- Permits are needed to set up the equipment and may be difficult to obtain from authorities.

- Remote sensing cannot cover 100 per cent vehicles in given program area. This raises concern on data representativeness of remote sensing program.
- The uncertainties of remote sensing are relatively large compared with laboratory emission testing and PEMS.

27. WHAT IS THE AUTOMOTIVE INDIAN STANDARD–170 COVERING REMOTE SENSING ACTIVITIES IN INDIA?

Automotive Indian Standard–170 have been developed by the Ministry of Road Transport and Highways for defining the scope of RSD implementation in India. Some of its features are as follow:

- AIS 170 defines the RSD equipment device specifications such as equipment range and accuracy for emission pollutants. The specifications define device's emission measurement capabilities to be followed while implementing RSD programmes.
- It also defines different standards such as IS/IEC 60529 (for ingress protection), IEC 61000 (Electromagnetic compatibility) that device must comply.
- AIS 170 defines the list of parameters such as emission measurements, vehicle registration details, operating conditions, time and date of measurement, RSD device details etc. that shall be recorded in RSD programme evaluation studies.
- It gives a list of IT hardware and infrastructure required to set up the device at the monitoring station.
- It gives the requirement on how and at what frequency the RSD device should be calibrated, a failure of which may affect the device accuracy to measure pollutants.
- It gives the steps required to properly set up the devices at the site.
- It gives an indication on how valid and invalid vehicle records are classified.

28. WHAT ARE THE GAPS IN AIS 170?

- The procedure does not elaborate on consideration to be followed while choosing remote sensing sites. The document also does not define what data analysis needs to be carried out for effective monitoring of remote sensing programme.
- The procedure fails to classify different remote sensing technologies that are available in the market and what technologies will be best suited for India. For some of the current RSD technologies equipment calibration is not required

as they are based on different measurement principle. However, the document has generically covered all equipment as having the requirement of periodic calibration.

- It does not give any details on how emissions cut points, above which a vehicle is considered high emitters, are defined.
- The document lacks in providing clear guidelines on how PUC and remote sensing can co-exists and if the vehicle needs to pass both to remain road worthy.
- AIS 170 document is not clear on regulatory action to be taken in case if the vehicle is identified as high emitter. The lack of clear legal framework will slow the technology adoption and causes legal dispute between vehicle owners who think that their vehicle has valid PUC certificate and authorities who had identified vehicle as high emitter through remote sensing device.
- AIS 170 document does not provide details on how the computer system at monitoring site should communicate with VAHAN database. Nor it gives any details on technology requirements from NIC (National Informatics Centre) to be followed if some entity wants to access VAHAN data for implementing remote sensing program.

As ICCT has further recommended with respect to AIS 170, it is crucial that the draft makes it mandatory to measure absorption. RS does not measure tailpipe concentration directly. It is recalculated from the pollutant/ absorptions ratio (and only done correctly for stochiometric engines, therefore not for diesels). Without absorption, pollutant absorptions alone are hardly useful. ICCT also recommends making NO measurement mandatory, as well as primary NO_2. Modern diesel can emit up to 50 per cent of NOx as NO_2. There can be a risk that RS with NO, but without NO_2, will underestimate real-world NOx emissions of diesel vehicles.

AIS 170 document should comprehensively address the challenges posed by model engine technology. In view of this national regulations for vehicle emission monitoring using remote sensing should be prepared that provide guidelines on how to implement remote sensing program in India. Cities that want to carry out remote-sensing programs will refer to the national regulation to screen for and take actions against non-compliant high-emitting diesel vehicles. The standardized remote sensing data can also be used for purposes that are not covered in the regulation, such as fleet screening, evaluating the in-use vehicle emission level, and identifying high-emitting models that may have manufacturing defects.

29. HOW DOES RSD HELP TO ASSESS AND DEVELOP EMISSIONS FACTOR OF VEHICLES?

Systematic generation of emissions data can help to develop and validate emissions factors of different generation of vehicles. The emissions from a vehicle are influenced by different factors including, but not limited to, engine efficiency, type of fuel, driving pattern, vehicle maintenance, traffic, adulterated fuel, aging fleet, routes, passenger load, cargo load, management, urban planning, weather conditions among others. Special efforts are made by vehicle testing agencies from time to time to carry out proper loaded mode emissions tests on different genre of vehicles to develop emissions factors that are needed to estimate the trend in pollution load from vehicles. In fact, Automotive Research Association of India has developed such factors in India.

RSD creates the opportunity to validate such efforts and help assess emissions rates from vehicles to further help develop or amend emissions factors and enhance understanding of different weather and driving patterns on emissions rates. International Council on Clean Transportation (ICCT) has carried out extensive analysis of the RSD data in London and other cities of Europe including Zurich to highlight some of the dimensions related to emissions factors. Some of its highlights as well as those from other studies are captured here. This emissions profiling of on-road vehicles in European and US cities have brought out the dimensions of diesel gate.

Emission factor per vehicle category: Remote sensing data can be used to provide average emission rates for specific vehicle classes such as passenger cars, light duty commercial vehicles, heavy-duty etc. The average emission rate per vehicle class can be calculated in similar way as fleet average. Data on vehicle category is derived from vehicle registry. The representativeness can be increased by measurements at different sites, thus capturing a different fleet and different driving conditions. ICCT studies on RSD initiatives in London in 2012 shows petrol cars have NOx emissions rates below the fleet average. NOx emissions from the on-road diesel cars and heavy-duty vehicles are higher.

Emission factors by emission standards: Average emission rate of vehicle vintage meeting different emission standards can be determined by certified emission and compared with the emissions measured by the remote sensing device. For instance, the ICCT review of RSD measurements in London in 2012 and in Zurich in 2000–12 shows that in diesel cars, NOx emissions are increasing in the real driving mode even though technology pathways have improved with improvement in mass emissions standards. The high average emission level indicates that many manufacturers have car models with high on-road NOx emission rates. Comparatively, petrol cars are closer to the regulatory emission limit values.

Effect of ambient temperature on emission factors: Vehicle homologation testing is carried out at a standard air temperature of 20-30°C. However, remote sensing measurements can be carried out at varied ambient temperature conditions. For instance, several ICCT assessment includes the analysis of the measurement campaign in Gothenburg, Sweden, that was conducted between September and November 2016, with temperatures ranging from about 8°C to 25°C during the day. The ICCT review shows that the real-world NOx emission increased by 50 per cent for Euro 5 compliant vehicles when the ambient temperature reduced from 20°C to 10°C. This data also suggests that most vehicle manufacturers are inclined to turn off NOx control through EGR as the ambient temperature reduces.

Effect of exhaust aftertreatment deterioration on emission factors: Vehicles passing through remote sensing sites vary widely in age and mileage, allowing analysis of how emissions deteriorate over time. This data helps assess after-treatment durability under real driving conditions. The ICCT review of global RSD programs shows a significant rise in NO emissions from diesel vans and pick-ups with SCR systems in the US, with a 50 per cent increase in just three years for certain model years. Remote sensing offers age-specific emission rates and valuable data for assessing deterioration factors, enabling deeper insights into individual vehicle models and after-treatment technology performance.

Effect of driving conditions on emission factors: Remote sensing data is collected for a wide range of vehicle driving conditions measured in terms of vehicle speed and acceleration. The average of several thousand instantaneous emission rates from remote sensing is comparable to an emission rate averaged over a test cycle or test trip with a few thousand second-by-second readings. Studies have compared the on-road NOx emission rate of diesel Euro 4 cars measured remotely in Zurich (campaigns 2011 to 2014) (Borken-Kleefeld, Franco, and Chen, 2015) with the modelled emission rate derived from the emission factor database, HBEFA 3.2 (HBEFA 3.2 2014) as a function of engine load. The emission rate per kilogram of fuel burned scales linearly with engine load for Euro 4 compliant cars. The key advantage of remote sensing is that emission rates are not bound to any specific cycles. The measurement of emissions from off-cycle or cycle engine operating points are possible with RSD. This can help to indicate the potential of emissions outside the regulated range of the RDE test trip window remain within bounds or not. The RSD data also demonstrates the difference in emissions performance of smaller diesel engines (below 2 litres capacity), and larger diesel engines (greater than 2 litres capacity).

30. HOW DO WE UNDERSTAND RSD DATA REPRESENTATIVENESS?

Remote sensing campaigns can cover a wide range of driving conditions that affect emissions performance. Therefore, it is important to choose a variety of measurement sites to capture different ranges of driving and ambient conditions relevant to urban emissions. Experts advise that sites selection therefore should not create systemic bias in the data based on driving conditions, vehicle attributes, sampling characteristics for different emissions standards and fuel types. It is important to measure at all the driving conditions of interest and measure at adequate number of sites which is also adequately distributed so that individual sites cannot have disproportionate impact on the global sample. A wide range of driving conditions have been captured in remote sensing measurements in Europe. This also bears out the relationship between ambient temperature, acceleration, and speed.

Remote sensing can estimate emissions under a variety of conditions, allowing an assessment of emissions by VSP, ambient temperature, and other variables. The samples generally have a fairly clear central tendency regarding ambient temperature, VSP, and acceleration and speed.

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