April 5, 2022

Best Practices for Implementing Heavy-Duty Vehicle Inspection and Maintenance Programs

Prepared for the Ozone Transport Commission by ERG

Contents

List of Abbreviations

AED	Air Enforcement Division
ARB	California Air Resources Board
CAN	Controller Area Network
CC-ROBD	Continuously connected remote on-board diagnostics
DTC	Diagnostic Trouble Code
EGR	Exhaust gas recirculation device
EDL	Electronic data logging
ELD	Electronic logging device
EPA	Environmental Protection Agency
FMI	Failure mode identifier
HD	Heavy-duty
HDV	Heavy-duty vehicle
HEAT EDAR	Hangar Environmental and Atmospheric Technology Emission Detection and Reporting
I/M	Inspection and Maintenance
LD	Light-duty
LDV	Light-duty vehicle
MD	Medium-duty
MY	Model year
MIL	Malfunction indicator light
MOU	Memorandum of understanding
MOVES	Motor Vehicle Emission Simulator
NAC	NOx absorption catalyst
NCC-ROBD	Non-continuously connected remote on-board diagnostics
OC	Occurrence count
OBD	On-board diagnostics
OEM	Original equipment manufacturer
OTC	Ozone Transport Commission
OTR	Ozone Transport Region
OHMS	On-road heavy-duty vehicle emissions monitoring system
P-DTC	Permanent Diagnostic Trouble Code
PFC	Permanent fault code
PGN	Parameter group number
PEAQS	Portable emissions acquisition system
RSD	Remote sensing device
SAE	Society of Automotive Engineers
SIP	State implementation plan
SPN	Suspect parameter numbers
VVT	variable valve timing

1. Executive Summary

Inspection and maintenance (I/M) programs for light-duty (LD) vehicles (gross vehicle weight rating, or GVWR, under 8501 lbs.) have been in place in the United States since the 1970s, with a proliferation of test types and standards driven by Clean Air Act requirements for areas out of compliance with ambient air quality standards. Most light-duty I/M programs have migrated towards reliance on vehicle on-board diagnostic (OBD) systems to determine emissions compliance, either in total or as part of a hybrid program that also includes exhaust tests. Prior to introducing OBD technology to the heavy-duty (HD) vehicle fleet (over 14,000 lbs. GVWR), I/M testing of these vehicles in the United States has been limited. HD I/M tests have typically consisted of idle testing, and/or using the SAE J1667 snap-idle opacity test. Many OTC states have some form of both LD and HD I/M program, although none have formally adopted OBD-based program for HDVs. In 2013, the Environmental Protection Agency (EPA) published a best practices memo outlining how to address OBD readiness issues for LD and medium duty (MD) diesel vehicles (8501-14000 lbs. GVWR) to assist states interested in including these vehicles in their OBD I/M programs. There is increased interest among states to implement OBD testing on HD vehicles over 14,000 lbs GVWR as well, following California's lead in establishing a next-generation HD I/M program. Eastern Research Group (ERG) developed this white paper at the request of OTC as a resource for member states to understand current best practices in vehicle I/M programs, focusing on HDs and drawing from developments with California's program.

There are significant differences between LD and HD fleets that require new and different approaches for HD I/M to be effective. Many LD programs don't include diesel vehicles; are designed for vehicles under 8,500 lbs; and employ a variety of test types (e.g., idle, dyno, or OBD), standards, and networks (for testing and repairing). The broad issues that needed to be considered in establishing or expanding a HD I/M program are:

- **Program Type Considerations:** The type of inspection network and vehicles to be included in the program are the foundation of the program and will be influenced by the presence of existing I/M programs.
- **Program Enforcement and Compliance:** Will the program be enforced via registration denial, roadside pullover, remote sensing measurement, or some combination of these strategies?
- **Test Procedure Considerations:** Will the program center on opacity tests, OBD, or some combination?
- **Coverage:** Which weight classes and model years are included in the program and how are out-of-state vehicles addressed?
- **Repair Support:** How will inspectors and repair professionals be guaranteed the necessary tools to conduct successful tests, diagnose and repair problems?
- **Potential Emissions Benefits/Quantification:** How will the benefits of the program be assessed?

Consideration of expanded HD I/M in the northeast can be informed by California, where the Air Resources Board (ARB) is preparing to implement an HD I/M program with an OBD test component applicable to diesel-powered trucks with engines of model year 2013 or newer. Planning, designing, and implementing ARB's HD I/M program has involved several stakeholder workgroup meetings and public workshops, during which ARB has sought input from interested and affected parties. ARB has adopted a novel test design for their HD I/M program. Although the program's design is not yet finalized and is still subject to change, it is currently being implemented with various decentralized-style test options intended to minimize burden on HDV drivers and commercial fleets. Test systems planned for the ARB program collect and transmit raw OBD stream (hex) data to the program database via the test systems, and test determinations are made centrally on the program server managed by ARB (or ARB's contractor). Program participants would then log into their account after a test has occurred to determine their test disposition and receive an electronic compliance certificate (if the test is deemed compliant). With limited exceptions, all HD diesel vehicles that travel on California roads will be required to comply with the HD I/M program, regardless of their registration or domiciled location. California is also working through key issues of HD I/M "readiness", pass/fail determination, and fraud identification or prevention that can inform OTC states' consideration of HD I/M program design.

Drawing from I/M best practices and lessons learned as California develops their next-generation program, there are several recommendations for OTC states to consider when implementing an HD I/M program:

- Build on collaboration among northeastern states to coordinate the expansion of HD I/M.
- Include a tampering/fraud identification component in HD I/M programs.
- Conduct pilot studies to better define equipment and program requirements, and gather data on potential program effectiveness.
- Assist EPA in quantifying HD I/M emissions benefit for regulatory inventories and potential SIP I/M credit.
- Begin implementation with flexibility and initially lenient criteria that can be modified over time to aid public and stakeholder acceptance (i.e., plan for a learning curve).
- Build IT and data infrastructure needed to support the program.
- Connect with California on lessons learned with ongoing program piloting and implementation.

2. Introduction and Background

ERG developed this white paper at the request of OTC[1] as a resource for member states to understand current best practices in vehicle I/M programs, focusing on HDVs. In developing this paper, ERG draws from over thirty years' experience evaluating and improving I/M programs, including supporting ARB in crafting the most comprehensive HD I/M program in the United States.

> In this document, OBD refers to the Society of Automotive Engineers (SAE) J1939 and SAE J1979 protocols, which are most used in late-model on-road HDVs operating in the United States.

I/M programs for LDVs have been in place in the United States since the 1970s, with a proliferation of test types and standards (cutpoints) driven by Clean Air Act requirements for areas out of compliance with ambient air quality standards. Most LD I/M programs have migrated towards reliance on vehicle OBD systems to determine emissions compliance, either in total or as part of a hybrid program that also conducts exhaust tests. Prior to introducing OBD technology to the heavy-duty fleet, I/M testing of these vehicles in the United States has been limited. For HD gasoline vehicles, I/M tests have typically consisted of idle testing, as dynamometer testing is impractical and most of these vehicles were not certified on a chassis-based test. Testing of HD diesel vehicles has most frequently been done using the SAE J1667 snap-idle opacity test. Many OTC states have some form of both LD and HD I/M program (Appendix A), although none have formally adopted OBD-based program for HDVs. In 2013, EPA published a best practices memo outlining how to address OBD readiness issues for diesel vehicles under 14,000 GVWR to assist states interested in including these vehicles in their OBD I/M programs. At this time, a handful of states are performing OBD testing on these vehicles, but there is increased interest among states to implement OBD testing on HDDV over 14,000 GVWR.

This paper is organized to first address general I/M issues before delving into the details of HD I/M. Section 3 covers general issues to consider when implementing HD I/M programs, such as program type, test procedures, coverage, repair, and quantification of benefits. Section 4 then focuses on HD OBD I/M test protocol in detail, first outlining the unique aspects of HD OBD testing and providing a detailed discussion of the design, planning, and implementation of ARB's proposed HD I/M program. The remainder of Section 4 is focused on HD I/M test fraud and tampering, with several detailed examples. Section 5 summarizes recommendations and best practices for OTC states to consider when establishing and maintaining HD I/M programs.

3. General I/M Issues

LD I/M was mandated in the 1990 Clean Air Act Amendments for specific nonattainment areas, and much of the experience gained from implementing and operating LD programs can be applied to HD I/M testing. However, there are significant differences between LD and HD fleets that require new and different approaches for HD I/M to be effective. For example, LD programs typically don't include diesel vehicles;

[1] The Ozone Transport Commission is an air quality consortium composed of air agencies from Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.

are designed for vehicles below 8,500 lbs.; and employ a range of test types (e.g., idle, dyno, or OBD), standards, and networks (for testing and repairing). Based on lessons learned from LD I/M implementation, this section addresses several issues to be considered in the design of HD I/M programs:

- Program Type Considerations
- Program Enforcement and Compliance
- Test Procedure Considerations
- Coverage
- Repair Support
- Potential Emission Benefits/Quantification

As was the case for LD I/M, new procedures and best practices will be developed over time, and in some instances, through trial-and-error during the early stages of the HD I/M learning curve. Procedures or policies that are successful in one state may be more difficult to implement in another state, depending on the existing I/M regulation, infrastructure, and policies already in place.

3.1. Program Type Considerations

Two important program elements to consider are the test network type and which types of vehicles will be subjected to testing. This section provides a description of the network types to consider for HD I/M testing and short summary of the GVWR classes considered to be medium-duty (MD) and HD by ARB and EPA.

Network Type

Areas that have an existing LD I/M program and are considering implementing HD I/M will already have a test network in place. Thus, their first option would be to add an HD element of the program into the existing structure. If the existing I/M program is decentralized, then the HD I/M program would also be decentralized, and the same logic would apply for centralized or hybrid programs. Adding the HD I/M testing to the existing network would require that the test facilities in the network have sufficient space to accommodate the larger vehicles, and that the location has adequate coverage for the HD fleet. California's proposed HD I/M network could also be considered decentralized; however, it will be significantly different than a LD decentralized testing network, as most testing will likely be done through telematics, kiosks, certified testers-for-hire, or by the fleets themselves. These testing approaches are described in detail in Section 4.

Gross Vehicle Weight Rating

Table 3-1 shows OBD implementation schedule by weight class and model year per ARB and EPA requirements. As shown, EPA certification standards required model year (MY) 2007 MD vehicles from 8,500-14,000 lbs. GVWR to be fully OBD compliant. OBD compliance for vehicles over 14,000 lbs. GVWR is required for MY 2010 for the engine family with the highest projected weighted sales, with additional engines being phased into compliance through MY 2013. The California certification process followed a slightly different timeline, although EPA has been moving toward harmonization with ARB compliance[2].

Table 3-1. California and Federal OBD Compliance Full Implementation Dates

GVWR (lbs.)	ARB Full	EPA Full
MD (8501-14,000)	Truck MY 1997[3]+	Truck MY 2007[4]+
HD (14,001 +)	Engine MY 2013[5]+	Engine MY 2013[6]+

Testing vehicles prior to full compliance dates may result in some vehicles being non-compliant or partially compliant. If a state decides to test pre-compliant vehicles, some mechanism should be employed to ensure vehicles are not inappropriately failed. As described in Section 4, this also applies to a small sample of “OBD deficient” vehicles that can exist for several years after the full compliance date.

3.2. Program Enforcement and Compliance

This section discusses the different methods typically used for I/M enforcement and compliance.

Registration Denial or Sticker Enforcement

Registration denial and/or sticker enforcement have typically been viewed as the best ways to ensure motorist compliance with LD I/M program requirements, and all 13 of the OTC I/M programs use at least one of these methods. It should be possible to use these same procedures and policies to help enforce HD I/M compliance, although state-specific programs would not apply to out-of-state trucks unless a reciprocity agreement were in place, as done for HD opacity testing in a 1999 Memorandum of Understanding (MOU). When registration is denied, a vehicle cannot be registered in an I/M area without demonstrating proof of compliance with all I/M program requirements (e.g., a passing OBD test). Typical requirements for registration-based enforcement include confirming the vehicle’s compliance status, dating the compliance certificate, and issuing citations for operating a vehicle with expired or missing license plates or an expired registration. An I/M sticker-enforced program would require a sticker be displayed to demonstrate I/M compliance, separate from the registration sticker.

Roadside Pullover

Another enforcement mechanism is pulling vehicles off the road and to perform a roadside inspection, or spot-test. In LD I/M, this is usually not well accepted by the public and therefore has not often been used outside of California. There are ready opportunities for such checks on HDVs, however, via existing roadside opacity inspections, where OBD testing could be included relatively easily; or required stops at weigh stations. During weigh station stops it is possible to verify the registration and/or I/M compliance sticker, and the vehicle could also receive an OBD test given the short duration of the test. Roadside

---

[2] OBD compliance requires the vehicle to meet the Society of Automotive Engineers J1979 or J1939 standard. These are discussed more fully in the HC I/M Issues section later in this paper.

[3] https://www.transportpolicy.net/standard/us-on-board-diagnostics/

[4] “On-Board Diagnostic (OBD) Regulations and Requirements: Questions and Answers”, EPA420-F-03-042, Dec 2003

[5] https://dieselnet.com/standards/us/obd_ca.php

[6] https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-control-air-pollution-new-motor-vehicles-and

pullovers can be treated as enforceable if law enforcement is on hand to issue tickets, or merely a check to catch those vehicles that have evaded the registration denial or sticker enforcement.

Remote Sensing and/or License Plate Capture

The original intent of remote sensing was to measure vehicle emissions in a real-world setting operating under actual driving conditions. When it was first deployed, the camera technology needed to capture license plate information was not nearly as accurate and reliable as it is today. Remote sensing can now also be used as an enforcement check in a registration denial program as the captured image of the vehicle's license plate can be cross-checked with the registration database to confirm the vehicle has met the I/M requirement. Like roadside pullovers, this is not truly an enforcement mechanism, but rather a check to catch vehicles operating in the area that are not properly registered. Automated License Plate Recognition is another option to assess compliance without measuring emissions.

3.3. Test Procedure Considerations

SAE J1667 (Opacity)

The SAE J1667, or snap-idle opacity test, has been used for many years to test diesel vehicles in an I/M setting, though the EPA's regulatory model MOVES currently does not provide any emission benefit estimates for performing an opacity test. Correlating the results of an opacity test with actual gaseous or particulate emission reductions has been very challenging. As new HDV certification standards have become more stringent and diesel engines have become cleaner, developing such correlations has only become even more difficult. If a state already has opacity test equipment, it may decide to continue using it on pre-OBD vehicles, especially if a significant share of their MD/HD fleet is not OBD- equipped. However, it may not be an efficient use of resources to purchase new or additional opacity test equipment with the implementation a new OBD-based HD I/M program as the number of HDVs subject to opacity testing will decline over time.

OBD

The highest percentage of OBD compliance will be achieved testing MD vehicles and HDVs with vehicle/engine model years after their full compliance date, as shown in Table 3-1. It is possible to test earlier model year vehicles using OBD; however, not all of them will be fully OBD compliant, so the program would have to develop a methodology to use partial compliance or bypass the OBD test for non-compliant vehicles. This will require additional resources and effort, but it would also allow all vehicles that are OBD-equipped to be tested. For non-OBD-equipped vehicles, the state could perform an opacity or idle test if such testing is already available in the program.

3.4. Coverage

In-State

The 1990 Clean Air Act Amendments established the Northeastern United States as an ozone transport region (OTR). This OTR includes all the OTC states and the District of Columbia, except for Virginia. The Virginia LD I/M program only covers northern Virginia as described in the most recent 2021 I/M Solutions

Jurisdictional Report[7]. Within OTC, the Maryland and Pennsylvania programs are not state-wide; therefore, it is not clear if there is legal authority to enforce HD I/M over the entire OTR.

Out-of-State

In 1999, a subset of nine OTC states signed a MOU for HD opacity which is meant to provide reciprocity related to opacity and FMCSA safety testing, though the efficacy of the MOU is limited due to state jurisdictional issues and in practice may not be invoked often. For example, Massachusetts provides a form that vehicle owners can fill out to notify the state that a vehicle was inspected out-of-state, but to staff knowledge this has not been requested for vehicles with GVWR over 10,000 lbs.[8] However, as an expanded HD program in the region is being considered, the consistency and collaboration promoted by this agreement will be important to build on. The question of how many HD trucks travelling within a given state are from out-of-state is paramount in understanding the efficacy of state-specific programs, and utility of reciprocity with neighboring states. Remote sensing device (RSD) camera technology and GPS-based "telematics", required on HD trucks via electronic data logging (EDL) requirements, can be helpful in tracking HDV movement throughout the state and aid in estimating the amount of time a vehicle spends in each state.

3.5. Repair Support

As with LD I/M, HD I/M repair support should include adequate training for all repair technicians that perform emission control repairs, and the state should assist the repair industry with information related to HDV diagnosis and repair, along with any technical and legal questions that may arise. For LD I/M, repair technicians are encouraged to have an Automotive Service Excellence (ASE) L1 certification to repair gasoline vehicles and an ASE A9 certification to repair LD diesel vehicles; however, HD repair mechanics should have an ASE L2 certification. Mechanic certification has been used as a metric in LD I/M to provide vehicle owners with information on the success of individual service facilities in repairing vehicles to pass, often called a repair report card. Another feature common to LD I/M programs is referee testing for motorists to address dispute resolution and issue vehicle waivers. Such support would also be recommended for HD I/M.

Given that HD truck owners generally rely on their vehicles as a primary source of income, it is likely they already have an established close working-relationship with a repair facility, and this may provide added impetus for the repair facility to tamper with the vehicle's emission control system to avoid meeting the HD I/M requirements. This needs to be considered in setting up such a program.

3.6. Potential Emission Benefits/Quantification

Though the EPA MOVES model provides an estimate of LD I/M program benefit for use in air quality planning, there are currently no direct method to use OBD data to independently verify emission benefits of and I/M program. This is because OBD systems do not provide direct data on the emission increase resulting from emissions component malfunction, instead flagging only that component degradation or

[7] https://www.obdclearinghouse.com/IMSolutions/#

[8] https://www.mass.gov/doc/out-of-state-verification-inspection-form/download

failure has triggered a pre-set threshold that infers higher emissions. Independent measurement of fleet emissions before and after the implementation of I/M OBD, or on individual vehicles before and after repair, can provide data needed to quantify program benefit. Remote sensing measurements with adequate sample size and repeat measurement could provide a direct emissions measurement and obtain actual emission measurements on the HD fleet.

The two traditional roadside remote sensing methods used in LD that can also be applied to HD are the infrared or ultra-violet-based RSD device and the Hager Environmental and Atmospheric Technology (HEAT) Emission Detection and Reporting (EDAR) device. Both methods can measure vehicle emissions in a real-world setting without needing to control or limit the vehicle's normal operation during the measurement process. Alternatively, two similar measurement approaches that employ portable emissions analyzers rather than RSD can also provide HDV emissions data in the field, although they are more intrusive in requiring that trucks be operated at specified driving conditions for 5-10 minutes. The first of these is the on-road Heavy-Duty Vehicle Emissions Monitoring System (OHMS), which uses measurement methods similar to those used in the HEAT RSD device while the vehicle is run through a partially enclosed space for approximately eight seconds. The other system has been developed by ARB and is known as Portable Emission Acquisition System (PEAQS). Like the OHMS procedure, the emission measurements are taken in a controlled setting, such as a HD weigh station. ARB is evaluating PEAQS as a tool for HD in-use compliance and enforcement.[9]

Emissions data collected using any of these remote sensing methods would be analyzed similar to how it is handled in LD analyses – comparing emissions before and after I/M to provide an estimate of the program's air quality benefit. EPA recently issued additional program evaluation guidance[10] that outlines best practices for reporting I/M data by model year, vehicle type, and the number and percentage of vehicles. Although this guidance was provided for LD I/M reporting, much of it is applicable to HD I/M and should be used accordingly wherever possible.

4. HD I/M Issues

Building on the general design considerations discussed in the prior section, this section takes a deeper look at HD OBD I/M testing. It begins with an overview of ARB's current vision for the upcoming California HD OBD test program, followed by approaches that may be used for HD OBD readiness and pass/fail criteria. The section concludes with information on approaches to address HD OBD program fraud, tampering, and non-compliance.

4.1. Overview of California's Proposed HD I/M Program

ARB is preparing to implement an HD I/M program with an OBD test component in accordance with California Senate Bill 210. Information in this document is tailored around approaches ERG has presented

[9] https://www.fleetmaintenance.com/equipment/emissions-and-efficiency/article/21163100/carb-provides-update-to-hd-im-pilot-program-and-obd-specifications

[10] Guidance on Vehicle Inspection and Maintenance Test Data Statistics as Part of Annual I/M Reporting Requirements, EPA-420-B-20-033, May 2020.

to ARB for the HD OBD component of their planned program, which is applicable to diesel-powered trucks with engines of model year 2013 or newer with controllers that are HD OBD compliant (SAE J1939 DM5 OBD compliance value of 20 or SAE J1979 Mode 1/PID 1C OBD compliance=20[11]). Since engines are typically one model year older than heavy-duty vehicle ages, heavy-duty vehicle of model year 2014 and newer would be the target fleet. Manufacturers decide whether to utilize either J1939 or J1979-compliant systems.

As described previously, HD OBD compliance is required for both California and federally-certified trucks. However, our prior review of a small sample of trucks both within and outside of California suggests that some trucks with engines of MY 2013 may not have full OBD compliance (the percentage of these "OBD deficient" vehicles will likely diminish as vehicle model years increase). As shown in Table 4-2, DM5 OBD compliance is represented by Identifier H, and the applicable parameters required for this identifier (which include many of the parameters described in this document) are listed in Table 4-1. Analysis approaches could be tailored to accommodate trucks that are not HD OBD compliant, although the reduction in available parameters could result in less stringent test and verification criteria for those vehicles. Alternatively, to avoid the risk of assigning an incorrect test disposition, these vehicles could be excluded from the OBD test or test program.

Planning, designing and implementing ARB's HD I/M program has involved several stakeholder workgroup meetings and public workshops, during which ARB has sought input from interested and affected parties. Documents describing the evolving plans for this program are available on ARB's website[12], including a recent summary of the proposed program presented during the December 9th, 2021 board hearing[13]. A phased implementation approach[14] is planned which will provide ARB, program contractors, and the subject fleet time to transition into program compliance. ARB has also performed several HD I/M pilot studies[15] to assess the upcoming program. An overview of findings, including anticipated program fleet and motorist costs and air quality benefits, repair evaluations, OBD test feasibility assessments and evaluation of on-road emission measurement and enforcement approaches are available on ARB's website.

Test Procedures

ARB has adopted a novel test design for their HD I/M program. Although the program's design is not yet finalized and is still subject to change, it is currently being implemented with various decentralized-style test options intended to minimize burden on HDV drivers and commercial fleets. In general, the program testing will be administered via several test methods. One conventional method involves testing

---

[11] Emission-related parameter compliance requirements applicable to DM5 OBD Compliance status are listed in SAE J1939-73, Section 5.2.2, "Suggested Diagnostic Support", Tables 1 and 2.
[12] https://ww2.arb.ca.gov/our-work/programs/inspection-and-maintenance-program/Meetings-and-Workshops
[13] "Proposed Heavy-Duty Inspection and Maintenance Regulation, Board Hearing, December 9, 2021, available at https://ww3.arb.ca.gov/board/books/2021/120921/21-13-3pres.pdf
[14] https://ww2.arb.ca.gov/our-work/programs/inspection-and-maintenance-program/heavy-duty-inspection-and-maintenance
[15] https://ww2.arb.ca.gov/rulemaking/2021/hdim2021?utm_medium=email&utm_source=govdelivery

conducted by certified test personnel, likely fleet employees or "test-for-hire" contractors who utilize non-continuously connected remote OBD (NCC-ROBD) test devices. Other options for remote "self-testing" at kiosks have been discussed, although it's possible those services could be provided by mobile referee testing or other ARB or ARB-contractor services. Most vehicles will be required to receive two compliance certificates per year, so to minimize downtime, ARB is also providing an option for a continuously connected remote OBD (CC-ROBD) test option, which would be a telematics device, either original equipment manufacturer (OEM) or aftermarket to transmit each instrumented truck's data to ARB continuously or periodically on an established schedule. This data could then be integrated into a truck's electronic logging device (ELD). A provision for a compliance time extension for vehicles with emissions malfunctions will be granted for vehicles for which repair parts are not immediately available.

Data Collection

All truck testing equipment to be used in the ARB program must be ARB-certified, including NCC-ROBD and CC-ROBD test devices. However, unlike typical conventional I/M programs in which test data is collected, converted from hex data to engineering units, and then a test disposition is determined by the analyzer and then broadcast to the vehicle information database (VID); test systems planned for the ARB program collect and transmit the unconverted OBD hex data to the program database via the test systems, and test determinations are made centrally on the program server managed by ARB (or ARB's contractor). Program participants would then log into their account after a test has occurred to determine their test disposition and receive an electronic compliance certificate (if the test is deemed compliant). A preliminary draft data specification is available on the ARB website[16] which lists the SAE J1939 and SAE J1979 parameters of interest, along with examples of formats of data to be transmitted to the ARB server.

Out-of-State Compliance

With limited exceptions, all HD diesel vehicles that travel on California roads, including those registered out-of-state, will be required to comply with the HD I/M program, regardless of their registration or domiciled location. Planned approaches for enforcing program compliance include motor vehicle registration holds, on-road enforcement through remote emissions monitoring systems and automated license plate readers, on-road enforcement efforts conducted by the California Highway Patrol or other state personnel, and compliance verification requirements for freight contractors, brokers, and freight facilities.

4.2. I/M Testing Readiness Determination

As with light-duty programs, HDV readiness is an important I/M consideration to ensure vehicles with malfunctions are effectively identified and malfunctions are not concealed by "not ready" monitors. In the earlier days of OBDII test implementation in light-duty I/M programs, readiness posed a challenge due to nuances, or "exceptions", from vehicle-to-vehicle (such as specific vehicles resetting readiness on key off or having difficulty setting monitors). I/M programs frequently dealt with these situations through the use of updatable "exception" tables that would change test requirements for specific vehicles with known

[16] https://ww2.arb.ca.gov/sites/default/files/classic//msprog/hdim/meetings/20201116_hdim_obd_device_specs.pdf

readiness issues, and also differing readiness criteria based on vehicle model year. It's possible that readiness issues could occur for HD I/M programs as well, and in fact the complexity may increase due to multiple responding controllers on many HDVs. Table 4-1 lists the primary diesel monitors relevant for a readiness determination in a diesel HD I/M program. These monitors differ somewhat from the non-diesel monitors typically evaluated in light-duty programs, in particular for the technology-specific control systems. In general, non-diesel engines require catalyst or heated catalyst monitoring but no SCR or NMHC catalyst monitoring, oxygen sensor and perhaps oxygen sensor heater monitoring but no exhaust gas sensor monitoring, and evaporative system monitoring but no PM filter monitoring.

Table 4-1. OBD Diesel Monitors

Criteria for Determining Readiness
Misfire (Continuous)
Comprehensive Components (Continuous)
Fuel System (Continuous)
Exhaust Gas Recirculation / Variable Valve Timing
Particulate Matter Filter
Exhaust Gas Sensor
Boost Pressure System
NOx Aftertreatment / SCR
NMHC Converting Catalyst

Examples of OBD Readiness Determination Data

For SAE J1939, OBD readiness determination data fall under DM05 (PGN 65230), SPNs 1221 -1223. An image of DM5 data collected from the Engine 1 controller on an HD OBD compliant model year 2019 vehicle is provided in Figure 4-1.

```
DM05 - Diagnostic Readiness 1, Monitor status since DTCs cleared

SPN_1218        =                     0   Active Diagnostic Trouble Code Count
SPN_1219        =                     0   Previously Active Trouble Codes
SPN_1220        =                HD OBD   OBD Compliance
SPN_1221        =             0000 0111   Continuously Monitored Systems Support/Status
SPN_1221_SUP    =             supported   Misfire monitoring Support
SPN_1221_STAT   =         test complete   Misfire monitoring Status
SPN_1221_SUP    =             supported   Fuel system monitoring Support
SPN_1221_STAT   =         test complete   Fuel system monitoring Status
SPN_1221_SUP    =             supported   Comprehensive component monitoring Support
SPN_1221_STAT   =         test complete   Comprehensive component monitoring Status
SPN_1222        =   0001 1110 1110 0000   Non-continuously Monitored Systems Support
SPN_1223        =   0001 0100 0000 0000   Non-continuously Monitored Systems Status
SPN_1222_SUP    =             supported   EGR system monitoring Support
SPN_1223_STAT   =         test complete   EGR system monitoring Status
SPN_1222_SUP    =             supported   Exhaust Gas sensor heater monitoring Support
SPN_1223_STAT   =         test complete   Exhaust Gas sensor heater monitoring Status
SPN_1222_SUP    =             supported   Exhaust Gas sensor monitoring Support
SPN_1223_STAT   =         test complete   Exhaust Gas sensor monitoring Status
SPN_1222_SUP    =         not supported   A/C system refrigerant monitoring Support
SPN_1223_STAT   =         test complete   A/C system refrigerant monitoring Status
SPN_1222_SUP    =         not supported   Secondary air system monitoring Support
SPN_1223_STAT   =         test complete   Secondary air system monitoring Status
SPN_1222_SUP    =         not supported   Evaporative system monitoring Support
SPN_1223_STAT   =         test complete   Evaporative system monitoring Status
SPN_1222_SUP    =         not supported   Heated catalyst monitoring Support
SPN_1223_STAT   =         test complete   Heated catalyst monitoring Status
SPN_1222_SUP    =         not supported   Catalyst monitoring Support
SPN_1223_STAT   =         test complete   Catalyst monitoring Status
SPN_1222_SUP    =             supported   NMHC converting catalyst system monitoring Support
SPN_1223_STAT   =     test not complete   NMHC converting catalyst system monitoring Status
SPN_1222_SUP    =             supported   NOx converting catalyst and/or NOx adsorber system monitoring Support
SPN_1223_STAT   =         test complete   NOx converting catalyst and/or NOx adsorber system monitoring Status
SPN_1222_SUP    =             supported   Diesel Particulate Filter (DPF) system monitoring Support
SPN_1223_STAT   =     test not complete   Diesel Particulate Filter (DPF) system monitoring Status
SPN_1222_SUP    =             supported   Boost pressure control system monitoring Support
SPN_1223_STAT   =         test complete   Boost pressure control system monitoring Status
SPN_1222_SUP    =         not supported   Cold start aid system monitoring Support
SPN_1223_STAT   =         test complete   Cold start aid system monitoring Status
```

Figure 4-1. Example DM5 Data from Engine 1 on a Model Year 2019 Vehicle.

For SAE J1979, these parameters are available under Mode $01, PID 01 (similar to light-duty programs). Note that in SAE J1979, one bit field in the Mode $01, PID 01 response is an indicator of whether the vehicle is diesel (compression ignition) or gasoline (spark ignition), so the SAE J1979 responses to the Mode $01, PID 01 request will be tailored for diesel vehicles (whereas the irrelevant SI-based parameters will likely be listed as unsupported for SAE J1939 requests).

Both SAE J1939 and SAE J1979 also specify "cumulative" readiness parameters that may be considered as part of the readiness determination, which are listed in Table 4-2.

Table 4-2. Cumulative Readiness Parameters for HDV Diesel Vehicles

Cumulative Readiness Parameter	SAE J1939	SAE J1979
Kilometers since DTCs cleared	DM21 (PGN 49408), SPN 3294	Mode $01, PID 1F
Minutes since DTCs cleared	DM21 (PGN 49408), SPN 3296	Mode $01, PID 4E
Number of warm-ups since DTCs cleared	DM26 (PGN 64952), SPN 3302	Mode $01, PID 30

An example image of some DM21/26 cumulative readiness data collected from the Engine 1 controller on the same HD OBD compliant model year 2019 vehicle is provided in Figure 4-2. Note that not all DM26 fields are shown in Figure 4-2, as these excluded fields are trip-based and are less relevant for a readiness determination.

```
DM21 - Diagnostic Readiness 2

SPN_3069 = 0 km Distance Travelled While MIL is Activated
SPN_3294 = 2407 km Distance Since Diagnostic Trouble Codes Cleared
SPN_3295 = 0 min Minutes Run by Engine While MIL is Activated
SPN_3296 = 1568 min Time Since Diagnostic Trouble Codes Cleared

DM26 - Diagnostic Readiness 3, Monitor status this driving cycle

SPN_3301 = 0 s Time Since Engine Start
SPN_3302 = 4 Number of Warm-Ups Since Diagnostic Trouble Codes Cleared
...
...
```

Figure 4-2. Example DM21/26 Data from Engine 1 on a Model Year 2019 Vehicle

Either the individual monitor readiness status, the cumulative readiness status, or both could be used in I/M program readiness determinations.

4.3. Approaches for HDV Readiness Determination

Under a previous study, ERG analyzed HDV readiness results to determine initial readiness criteria in a HD I/M program. The summary of that analysis provided below helps illustrate various program implementation options.

Working with Results from Multiple Controllers

Since multiple controllers may respond to readiness queries, consideration of results from all HD OBD-compliant controllers is necessary to develop a complete readiness profile. Prior analysis has shown that OBD readiness support varied between controllers for different vehicles. For the J1939 data, readiness results were generally broadcast by the HD OBD compliant controllers (DM5 OBD compliance=20), while non-compliant controllers (those with DM5 OBD compliance values other than 20) generally did not broadcast readiness results.

For some vehicles, different controllers would report on different monitors (i.e., the controllers generally reported on their applicable monitors). For example, a vehicle might have:

- Controller “0” (engine #1) report “not supported” for all monitors;
- Controller “1” (engine #2) report on the continuous monitors (misfire, fuel system, comprehensive components), and the EGR/VVT and boost pressure control monitors; and
- Controller “3D” (Exhaust Emissions Controller) report on the Exhaust Gas Sensor, Exhaust Gas Sensor Heater, DPF and NMHC Converting Catalyst monitors.

A complete readiness determination therefore would require the I/M data collection process to gather and compile results from all active responding HD OBD compliant controllers prior to making a readiness determination. Controllers that were not HD OBD compliant were not found to provide accurate and complete readiness information, although this was not thoroughly evaluated. For the SAE J1979 data evaluated, only the engine controllers were HD OBD compliant, so a compilation of readiness results from multiple controllers has not been required for the sample of vehicle data ERG has analyzed thus far.

Since multiple controllers can respond (particularly for SAE J1939 vehicles), an opportunity exists for conflicting/contradictory results to be collected during readiness queries. These conflicting/contradictory results are disagreements between controllers for individual monitors (DM5) and for cumulative readiness results (DM21/26) for HD OBD compliant controllers on individual vehicles. Disagreement in this context can occur when one controller reports "supported and ready" and another controller reports "supported and not ready" for a particular monitor on the same vehicle, or if different values for the DM21/26 cumulative values are reported from different controllers on the same vehicle.

Although results from most vehicles with multiple HD OBD compliant controllers were consistent, some occasional data disagreements have been noted in prior analysis, with individual monitor agreement rates ranging between 84 percent and 95 percent (for HD OBD compliant controllers, $n \cong 350$ trucks). For DM21/26 cumulative readiness results, agreement among controllers for these parameters ranged from 84 percent to 95 percent for vehicles with HD OBD compliant controllers. The rate of conflicting results increased when data from controllers that are not HD OBD compliant are considered. It is likely that future HD I/M programs will encounter occasional DM5 monitor conflicts between controllers, or DM21/26 conflicts (differences in cumulative operation totals since reset). One approach for handling these differences is to default to the "least ready" result (i.e., not ready for that particular DM5 monitor, or the shortest operation for DM21/26). Software logic flexibility to handle conflicting results will be beneficial.

Using Cumulative Readiness and Individual Monitor Results

Another HD I/M readiness consideration is whether the needed parameters will be available from each tested vehicle to make an accurate readiness determination. Understanding how these data fields are populated and the prevalence of data omissions can help establish if cumulative readiness would be sufficient for a readiness determination, or if individual monitor readiness (either independently or used with cumulative readiness) are required for a readiness determination. While the two cumulative parameters of "DM21_Minutes since DTCs cleared" and "DM26_Number of warmups since DTCs cleared" appear to be frequently populated (98 percent and higher for the same sample analyzed), "DM21_Kilometers since DTCs cleared" was only found to be populated for a bit more than half the vehicles analyzed during prior analysis. Some OEM-specific trends were noted, but no definitive conclusions were made as to why this field was frequently unavailable. For the small sample of SAE J1979 vehicles, "PID 1F_Kilometers Since DTCs Cleared" and "PID 30_# of Warmups Since DTCs Cleared" were typically populated, but the support rate for "PID 4E_Minutes Since DTC Cleared" was just over 90 percent for the sample of vehicles with HD OBD-compliant controllers. Program (software) flexibility, and perhaps consideration of both individual monitors and cumulative readiness in the readiness determination, may therefore be the most effective approach in accurately determining readiness in a HDV I/M program. This could include the use of a primary readiness evaluation (such as cumulative readiness results) with a "fallback" method (readiness tally of individual readiness monitors) as needed (i.e., if the cumulative results are not available). Fewer assessments have been performed with readiness data from controllers that are not HD OBD compliant, so additional flexibility (and analysis of additional data prior to the start of an enforced I/M program) would be recommended if a program were to include non -compliant trucks in the OBD test program.

Program Adjustments over Time

As with light-duty programs, a HD I/M program's monitor readiness criterion may need to be changed over time as the program and vehicles evolve. When analyzing ARB's potential readiness criteria, ERG observed some unique trends. For example, HDV continuous monitors are occasionally "not ready", unlike continuous monitors in light-duty vehicles which are typically always "ready", so initial application of mandatory readiness for continuous monitors in the HD I/M program could result in unacceptably high "not ready" rates (some light-duty I/M program do not consider the status of continuous monitors in the readiness determination since these are typically always "ready"). Readiness criteria can be adjusted over time to tighten requirements as the program evolves, especially if readiness rates increase with newer model year trucks. Evaluation of individual J1939 monitor readiness rates showed roughly two unset continuous monitors and seven unset non-continuous monitors for HDVs that had just been reset (zero distance since last reset, n≅20 trucks). HDVs that had travelled between 200 and 300 km since the last reset had fewer than one continuous monitor and approximately four non-continuous unset monitors (n≅5 trucks), and HDVs that had travelled more than 1000 km since the last reset had approximately 0.2 continuous monitors (average) and approximately 0.75 non-continuous unset monitors (n≅200 trucks). These results included all trucks MY 2014 and newer, that were HD OBD-compliant. Similar trends were seen for SAE J1979 data, although the dataset was much smaller (approximately 35 trucks). Initiating a data collection program in which readiness is not enforced would provide program administrators the opportunity to collect a sufficiently large dataset in order to estimate an allowable number of "not ready" monitors for their program and to identify slower setting monitors (monitors that are most frequently not ready) if individual monitor readiness data are used in a vehicle's readiness determination. Also, as with light-duty programs, application of monitor-specific criteria for some non-continuous monitors, based on the initial failure, may be worthwhile. For example, ensuring a DM5 DPF monitor is "ready" for a retest of any prior DPF failure would help ensure DPF problems are not masked by unset monitors. In addition, consideration of requiring certain monitors to be "ready" on an initial test can help prevent compliance certificates from being issued for vehicles with pending failures (such as those that would arise from SCR malfunctions). Use of permanent fault codes (to be discussed in the next section) can also be of benefit in determining readiness and compliance, in particular in preventing not-ready vehicles with malfunctions masked by unset monitors from being passed or issued a compliance certificate. Although written for vehicles with a GVWR less than 14,000 lbs., EPA's March 07, 2013 memorandum entitled "Best Practices for Addressing OBD Readiness in IM Testing of Diesel Vehicles Under 14,000 Pounds Gross Vehicle Weight Rating" provides approaches for readiness and pass/fail criteria that could be tailored for a HD I/M program. Although this document does not appear to be available online, a PDF copy of this document may be made available, upon request.

4.4. I/M Testing Pass/Fail Determination

Similar strategies may be used for pass/fail determinations in a HD I/M program, although some nuances do exist due to multiple controllers, multiple communication protocols, and the difference in data formats between protocols. These approaches, and the differences in data between the two protocols, are provided in the following subsections.

SAE J1979

Aside from readiness and other I/M test criteria (such as a missing DLC, failure to communicate, MIL bulb check, etc.), criteria for LD I/M program pass fail determinations is typically straightforward and based on the malfunction indicator light (MIL) Status (Mode $01/PID 01) and presence of active diagnostic trouble codes (DTCs) (Mode $03 / PID 00). DTCs that are "pending" (Mode $07/PID 00) are unconfirmed, do not illuminate the MIL, and therefore are not used as a basis for failure, and historical codes are also inactive, do not command the MIL on, and not used as a basis for failure. Some I/M programs consider permanent fault codes (PFCs) in the pass/fail determination. LDV PFCs, typically available on MY 2010 and newer vehicles[17], are in a format similar to Mode $03 DTCs but are emissions-related codes that cannot be cleared with a scan tool reset command or battery disconnect, and therefore cannot be erased immediately prior to an I/M inspection. Enforcing PFCs (perhaps as part of the I/M program's readiness criteria) prevents a vehicle with a true emissions malfunction from passing the I/M inspection by "hiding" an erasable emissions-related fault through a scan tool reset. PFCs are automatically cleared by the vehicle's control module after the module confirms the problem that originally set the code no longer exists after specific driving and operating conditions necessary to verify proper functionality have been met in order to complete internal testing.

Use of PFCs in an I/M program's pass/fail determination creates the possibility of a powertrain or emission control system with a previous malfunction that originally set the PFC to now be functioning properly —no true emission-related malfunctions exist—but the vehicle has not been through the operating conditions required for a self-clear, so a "residual" PFC remains. In addition, vehicle monitoring logic anomalies could occur in which a PFC is stored, yet no active emissions-related faults are present on the vehicle. Consideration of cumulative and individual monitor readiness status (previously described) in the overall pass/fail determination can help reduce the likelihood of PFC errors of commission (false failures). The California Bureau of Automotive Repair (BAR) does not fail for PFCs in vehicles that have completed at least 15 warm-up cycles and have been driven at least 200 miles[18] since the most recent reset. Similar logic (perhaps with different limits to reflect HDVs) may be appropriate for a HDV I/M program that uses PFCs.

SAE J1939

SAE J1939 fault reporting differs from that used for SAE J1979. Rather than independently reported DTCs, faults (also sometimes referred to as DTCs in SAE J1939) are reported as suspect parameter numbers (SPNs) within a parameter group number (PGN) that indicates the type of fault (active, historical, emissions pending, emissions active, emissions historical, all pending faults, and emissions permanent). The SPNs used to report faults are the same SPN designation as the live operating parameters also reported (typically broadcast) by SAE J1939, although when reported within one of the aforementioned

[17] https://www.bar.ca.gov/pdf/PDTC_Workshop_Presentation_4.18.2018.pdf
[18] https://www.bar.ca.gov/Industry/PDTC

fault PGNs, they are also reported with a failure mode identifier (FMI) and an occurrence count (OC)[19]. The FMI designates the type of failure (i.e., voltage above normal, abnormal rate of change, data error, etc.) and the OC is a count of the number of times the failure has been identified. Figure 4-3 provides an example of DM1 from three control units (Engine #1, Engine #2, and the Exhaust Emissions Controller) on a model year 2020 vehicle with HD OBD-compliant controllers. As shown, the MIL is commanded off and no DTCs are stored for source address 0x00 (Engine #1), but Engine #2 (0x01) reports the MIL commanded on (SPN 1213=1) with an SPN of 639 (network communication error) with an FMI of 14 (this indicates "special instruction" per SAE J1939-73), and an OC of 1 (this happened one time). No faults are reported for source address 3D (exhaust emissions controller). Results from other controllers (not emissions related) are omitted from Figure 4-3. Of note is that an emissions-related fault from one controller with the MIL commanded on is sufficient for the overall truck MIL status (the controllers report independently, and not all controllers will necessarily command the MIL on).

[19] SAE J1939-73, Section 5.6, Diagnostic Trouble Code Definition.

```
DM1
 source address: 0x00
 pgn: 65226 (0xFECA)
 description: Active Diagnostic Trouble Codes (DTCs)
 data bytes: 03 FF 00 00 00 00 FF FF
 lampMalfunctionIndicatorStatus_1213: 0
 lampRedStopStatus_623: 0
 lampAmberWarningStatus_624: 0
 lampProtectStatus_987: 3
 flashMalfunctionIndicator_3038: 3
 flashRedStop_3039: 3
 flashAmberWarning_3040: 3
 flashProtect_3041: 3
 [no dtcs]

DM1
 source address: 0x01
 pgn: 65226 (0xFECA)
 description: Active Diagnostic Trouble Codes (DTCs)
 data bytes: 43 FF 7F 02 0E 01 FF FF
 lampMalfunctionIndicatorStatus_1213: 1
 lampRedStopStatus_623: 0
 lampAmberWarningStatus_624: 0
 lampProtectStatus_987: 3
 flashMalfunctionIndicator_3038: 3
 flashRedStop_3039: 3
 flashAmberWarning_3040: 3
 flashProtect_3041: 3
 dtc[0]
  [J1939 Network #1, Primary Vehicle Network]
  spn: 639
  fmi: 14
  oc: 1
  cm: 0

DM1
 source address: 0x3D
 pgn: 65226 (0xFECA)
 description: Active Diagnostic Trouble Codes (DTCs)
 data bytes: 03 FF 00 00 00 00 FF FF
 lampMalfunctionIndicatorStatus_1213: 0
 lampRedStopStatus_623: 0
 lampAmberWarningStatus_624: 0
 lampProtectStatus_987: 3
 flashMalfunctionIndicator_3038: 3
 flashRedStop_3039: 3
 flashAmberWarning_3040: 3
 flashProtect_3041: 3
 [no dtcs]
```

Figure 4-3. Example DM1s from Engine #1, Engine #2, and the Exhaust Emissions Controllers

A comprehensive list of SPNs can be found in SAE J1939DA[20], while the FMI designations are provided in SAE J1939-73, Appendix A. Table 4-3 lists the fault-reporting PGNs[21]:

[20] https://www.sae.org/standards/content/j1939da_202001/
[21] SAE J1939-73

Table 4-3. SAE J1939 Fault Reporting Parameter Group Numbers

PGN	DM (PGN acronym)	Parameter Group
65226	DM1	All Active DTCs
65227	DM2	Previously Active DTCs
65231	DM6	Emissions Related Pending DTCs
65236	DM12	Emissions Related Active DTCs
64949	DM23	Previously Active Emissions Related DTCs
64898	DM27	All Pending DTCs
64896	DM28	Emissions Related Permanent DTCs

All the DMs listed in Table 4-3 are provided in a format as shown in Figure 4-3. Except for DM1 (all active DTCs) which is a broadcast parameter, a request is required to obtain the other fault reporting PGNs shown in the table above (the analyzer requests the data from the responding controllers, which then provide a response). The ID of the fault message lists the controller from which the message was sent, with HDV emissions-related controllers typically being Engine #1 (controller 0), Engine #2 (controller 1), and the Exhaust Emissions Controller (Controller 61, or hex ID 3D). Other controllers could also broadcast readiness and fault data, so to obtain a complete profile of the HDV's readiness and fault status, review of the results of a full census of all responding controllers would be required, retaining results for controllers with HD OBD compliance[22].

Various options exist for consideration of the fault reporting DMs in pass/fail determinations, and these should be made in tandem with readiness considerations described in the prior section. DM1 is a listing of all active trouble codes, emissions-related and otherwise. Therefore, several SPNs with associated FMIs and OCs (hereafter referred to as faults) could be stored in DM1, and if any of them are emissions-related, the MIL will be commanded on. If more than one fault is stored in DM1 and the MIL is commanded on, without additional information it is unknown which faults are emissions-related. DM12 is intended to be the emissions-only subset of DM1, therefore any DM12 code should command the MIL on. However, this is not always the case, and occasionally DM12 faults are stored with the MIL commanded off, which could be interpreted as an OEM implementation issue (since an active emissions-related fault in DM12 would likely be sufficient to command the MIL on). Similarly, DM28 stores emissions-related permanent faults, although it's possible that a reset has recently occurred, erasing the active codes and hence MIL command, yet the permanent fault remains. Prior analysis has shown a small percentage of DM28 faults are stored with MIL commanded off.

As with light-duty programs, program acceptance issues can arise if fault-related failures occur without MIL illumination. One approach to avoid this would be to consider emissions-related active faults (DM12) with MIL command as a basis for failure, and apply readiness logic along with PFC evaluation as basis for test readiness. Therefore, HDVs with no active faults but with a PFC would not be eligible for a test (same ineligibility as with too many unset monitors). Logic similar to BAR's PFC logic (only consider PFCs if less than a specific number of warmups or miles travelled since last reset have occurred) would then prevent

[22] SAE J1939-73 Section 5.2.2, "Suggested Diagnostic Support", Tables 1 and 2.

“lingering” PFCs from inhibiting an otherwise “ready” vehicle from being tested. Also, as stated previously, results are analyzed on a “by-controller” basis, so all DM12/D28 results from all HD OBD-compliant controllers (DM05 OBD-compliance = 20) would be included in a comprehensive evaluation of readiness and pass/fail determination. As recommended for readiness, starting the program with lenient standards (perhaps only during a data collection period) will allow the program to better characterize the subject truck fleet and develop program logic that provides an acceptable balance between emissions benefit, industry burden and program acceptance. Alternatively, this could be performed in a few select states in order to develop more comprehensive guidance before widespread national adoption. Over time, the program can be tailored for the evolving fleet and may incorporate differing requirements for newer model-year HDVs versus older HDVs, based on variations observed in the fleet. Allowing program adjustments over time will ensure the program can be optimized as it and the subject fleet evolves.

4.5. Fraud, Tampering, and Non-Compliance

In November 2020, the EPA released a review[23] of aggregated evidence from EPA civil enforcement investigations to several state air agencies, including NESCAUM. Information in this report was based on approximately five years of investigations of tampering of Class 2b and 3 diesel pickup trucks. In summary, EPA’s Air Enforcement Division (AED) estimates that emission controls have been removed from more than 550,000 diesel pickups over the last decade, or approximately 15 percent of the trucks with emission controls in these weight classes. Due to the excess emissions from these removals, AED estimates this is equivalent to nine million additional (non-tampered) diesel trucks operating on U.S. roadways. This high prevalence elevates the importance of an effective tampering identification component in an I/M program. Additionally, manufacturer-enforced derates that occur when emission control malfunctions are left unaddressed may tend to shift the focus of I/M programs from emission fault detection to detection of efforts to conceal emission faults or bypass manufacturer-imposed emission control compliance. Reports of some investigations, including the tampering approaches and their emissions impacts, are also available on EPA’s website.[24]

Because of these issues, this section is intended to help clarify and identify the various types of tampering, so states will be better equipped to deal with this issue. A general overview of various forms of program non-compliance is provided, which includes modifying the powertrain in a way that could alter emissions, modifying the OBD system, and/or modifying or deleting emission control components. In this document, these alterations are generically referred to as tampering and are any alteration from stock configuration, excluding replacement of factory components with factory components or with components with emissions certifications, such as with components that have an EPA aftermarket parts certification or a ARB EO certification. Other forms of non-compliance, such as unauthorized on-road operation and emissions-inspection and/or registration avoidance, are also briefly discussed.

[23] https://www.epa.gov/sites/default/files/2021-01/documents/epaaedletterreportontampereddieselpickups.pdf
[24] https://www.epa.gov/enforcement/tampered-diesel-pickup-trucks-review-aggregated-evidence-epa-civil-enforcement

Emissions System Overview

The following subsections provide high-level overviews of the primary emission control components on a typical modern medium-duty (MY 2010 or newer) or heavy-duty (MY 2014 or newer) diesel truck. This information is intended to provide context regarding the types of powertrain and emission control component tampering typically performed. Figure 4-4 is a general schematic listing the various powertrain and emission control component systems typically utilized on on-road vehicles. The NOx adsorption catalyst (NAC) shown in Figure 4-4 is not common on diesel-powered HDVs, so these and three-way catalysts (gasoline-vehicle catalysts) are not addressed in this document. Similarly, physical modification of an engine's variable valve timing (VVT) system is not commonly performed, so any methods to modify exhaust gas recirculation via VVT would likely be through engine control (OBD) modification, and this form of electronic tampering will be addressed later in this document.

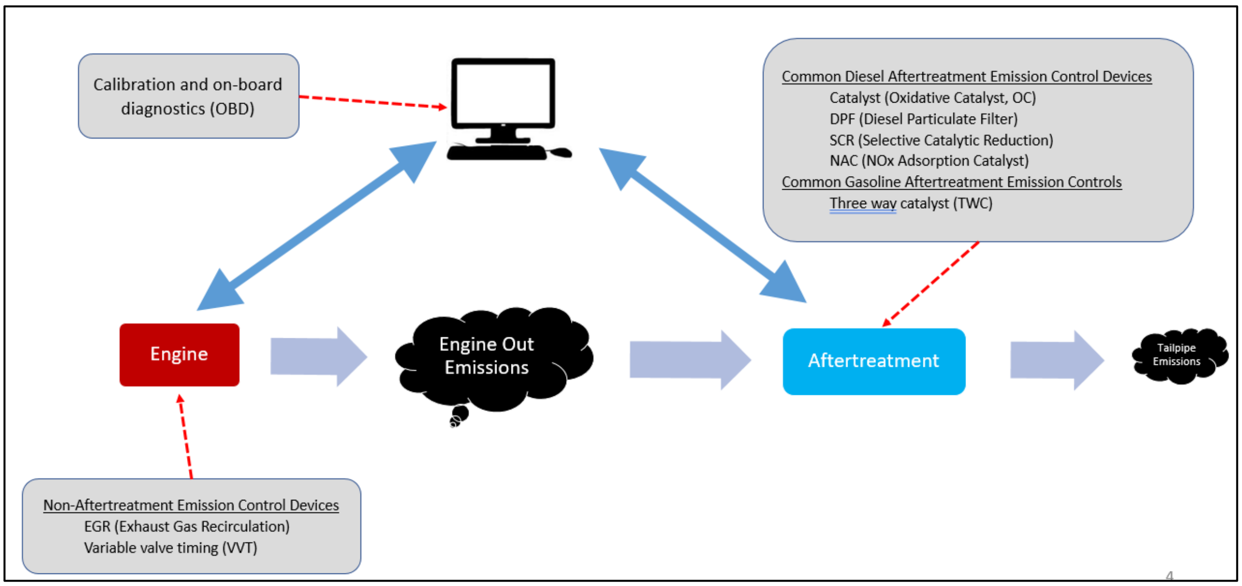

Figure 4-4. Common Emission Control Devices

Figure 4-5 is a simplified schematic of a modern diesel HDV powertrain and emission control system. The arrangement of components on any specific vehicle may differ from that shown in Figure 4-5.

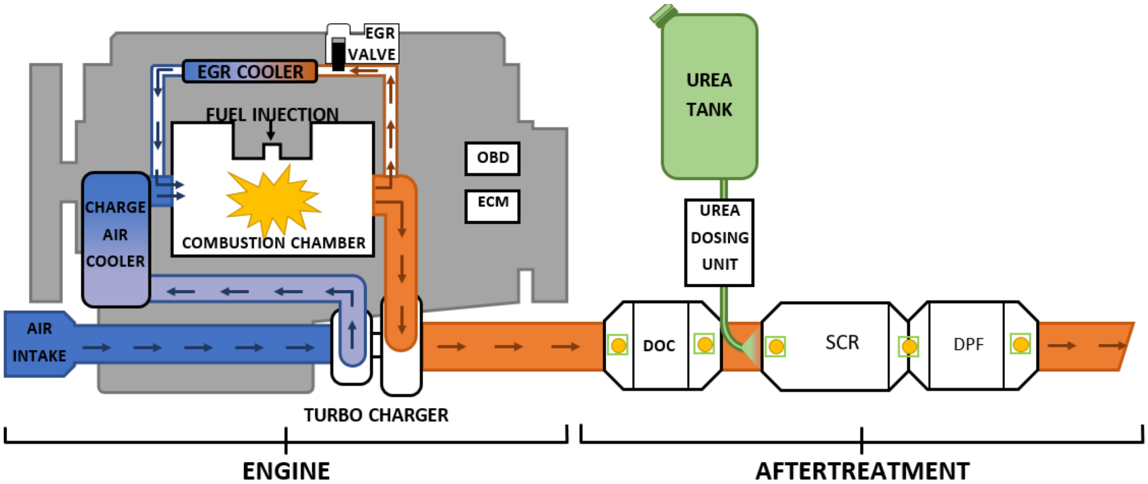

Figure 4-5. Typical Diesel HDV Emission Control System

Other emission control systems, such as crankcase ventilation systems, are not as commonly tampered and are not addressed here.

Table 4-4 lists emission reduction ranges and other details regarding the components shown in Figure 4-5.

Table 4-4. Common Diesel HDV Emission Control Components

Emission Control Device	**Ancillary components**	**Possible Pollutant Reductions (%)**	**Additional Notes**
Exhaust Gas Recirculation (EGR)	Charge Air Cooler (CAC)	NOx (25-40)[25]	Configurations vary, EGR functionality may also be accomplished internally via variable valve timing (VVT)
Diesel Oxidation Catalyst (DOC)		HC(40-75), CO(10-60), PM(20-40)[26]	Typically located in the same canister as the DPF (if the HDV is so equipped)
Diesel Particulate Filter (DPF)	Hydrocarbon (HC) injection system	HC(70-90), CO(70-90), PM(85-90)[27]	HC (diesel fuel) injection required for active regeneration
SCR	Diesel Exhaust Fluid (DEF) injection system	NOx(90), HC(50-90), CO(50-90), PM(30-50)[28]	DEF system consists of urea (DEF) tank, pump, injection apparatus, and other equipment

[25] Domenico, Oliveira, Sodre, Effects of EGR rate on performance and emissions of a diesel power generator fueled by B7, 2017
[26] Diesel Oxidation Catalyst General Information, Technical Bulletin EPA-420-F-10-031, US EPA
[27] Diesel Particulate Filter General Information, Technical Bulletin EPA-420-F-10-029, US EPA
[28] Diesel Technology Forum, "What is SCR?" available at https://www.dieselforum.org/about-clean-diesel/what-is-scr

Tampering Overview

Modifications can be made for several reasons, including attempts to increase performance, reliability, fuel economy, or uptime; reduce maintenance costs; or other reasons. Many of these modifications will have an effect on vehicle emissions. On computer-controlled and monitored vehicles, modifications typically involve some form of reprogramming (also referred to as “reflashing”) of one or more control modules, and these can be accompanied by other changes, such as the addition of performance hardware, modification or disabling of emission control components, and/or addition of component “emulators”, which are systems that generate signals to mimic factory components or systems that have been removed. Powertrain and emission control system operation may also be modified by interception and modification of electronic signals to or from a control module by an in-line device (a device directly wired into the controller area network (CAN) bus or connected to the vehicle’s diagnostic connector). In this document, replacement of a factory component with an equivalent factory component or a component that has an ARB or EPA emissions compliance certification, or reflashing with emissions-certified software, is not considered tampering.

Tampers may be strictly electronic (for instance, modifying fuel injection timing or disabling an exhaust gas recirculation valve (EGR), while others may also involve a hardware modification (such as removal of a DPF and/or SCR). However, hardware modifications may be concealed, for example by eliminating the DPF and/or SCR internal core structure but retaining the factory housing for a stock appearance, or installing an EGR block plate while retaining the factory EGR components in place over the plate. Because of this, review of data downloaded through the diagnostic port is an essential element of a thorough tampering inspection, particularly for HD OBD-compliant HDVs with engine MY 2013 or newer (for HDVs this is typically trucks of MY 2014 and newer, since engine year generally lags truck year by one).

5. Recommendations for OTC States Considering HD I/M

Drawing from I/M best practices and lessons learned from ARB’s program development, this section summarizes several recommendations for OTC states considering an expanded HD I/M program.

Build on collaboration among northeastern states to coordinate the expansion of HD I/M: Many HD trucks travelling on interstate highways in the region will be registered out-of-state, and may not be subject to a given state’s I/M requirements. The 1999 Regional Smoke Opacity Testing of Heavy-Duty Diesel Highway Vehicles MOU signed between nine northeastern states recognized the importance of interstate travel on regional emissions along with the need to coordinate HD inspection practices and coverage. This MOU promotes consistency in test protocols and cutpoints and reciprocity in accepting inspections conducted in cooperating states to reduce inspection burden on each individual state. As states consider strengthening HD programs around OBD, this coordination and collaboration should be reaffirmed through the planning, pilot, and implementation stages. Having this agreement in place from the start will improve consistency and efficiency as states work to evaluate and implement new program elements.

Include anti-tampering/anti-fraud component in HD I/M programs: EPA recently released a report suggesting approximately 15 percent of all Class 2b and 3 diesel pickup trucks are operating with some form of tampering. It's also likely that tampering is occurring in higher weight classes, as manufacturer-enforced deratings occur when emission control malfunctions are left unaddressed and force action (either a vehicle repair or a tamper to disable self-monitored emission control equipment). We therefore recommend that I/M programs implement approaches and procedures to identify and prevent tampering, both through visual inspection as well as through data analysis.

Conduct pilot studies: As described in this paper, implementation approaches for heavy-duty I/M programs will differ from those of light-duty I/M due to significant differences in equipment, data, and the target fleet. We recommend conducting pilot programs to better define equipment and program requirements. We also recommend public and stakeholder involvement to better understand the impact on the regulated industry and approaches for streamlining the program. Data collected during pilot programs may be used to better understand data patterns that could inform future readiness and pass/fail criteria, and to establish initial program criteria for implementation. Pilot programs also offer an opportunity to estimate HD truck emissions before-and-after repair, and the various facets of program costing, including not only test and repair costs but also costs on the state end (data collection, handling, program enforcement, quality control, etc.).

Assist EPA in quantifying HD I/M emissions benefit: The emissions benefit of OBD-based HD I/M and anti-tampering programs are not in the current version of MOVES (MOVES3), the EPA model required for states to use in estimating vehicle emissions for state implementation plans (SIPs) and to claim credit for emissions reductions programs. The inability to claim credit for HD I/M in SIPs poses a significant challenge that states face in funding and implementing these programs. The omission of these credits from the MOVES model stems from a historic lack of data on which to base credible reductions; however, EPA and ARB are beginning to conduct studies to fill this research gap. Data from pilot studies conducted by OTC states could also add to the body of evidence that EPA will consider for the next iteration of MOVES. We recommend querying EPA's Office of Transportation and Air Quality (OTAQ) on research plans and data needs with respect to HD I/M program benefit, and communicating pilot study findings when available. States may also be able to coordinate with ARB to gather additional information on how California will estimate these benefits with their EMFAC model.

Allow a learning curve for program development and implementation: Some elements of HD I/M programs will need to be developed during the pilot and development phases of the program, such as Initial pass/fail and readiness criteria, program integration with other agencies (e.g. state DMVs for registration enforcement), and the handling of out-of-state trucks. As with LD I/M, development of thorough system specifications and requirements and system certification and acceptance testing procedures are essential components of a smooth program implementation. We recommend programs be implemented with flexibility and initially lenient criteria that can be modified over time based on lessons learned from pilot and ramp-up phases. During the early stage of the program, integration of additional vehicle classes into the testing infrastructure and public acceptance are valuable objectives, which will allow increasing program stringency over time as more in-program data is collected and analyzed.

Identify data needed from DMVs to support development of a program: States which already have LD I/M program enforcement through registration denial can build upon existing knowledge and perhaps infrastructure as the HD I/M program is developed. The approach used will vary from state to state based on how the I/M IT infrastructure is managed (developed and managed in-house vs. contract). Thorough system and functionality specifications and certification testing for effective registration integration is recommended. Coordination and sharing of registration data between states will facilitate regional collaboration of HD I/M program enforcement.

Connect with California on lessons learned from ongoing program piloting and implementation: As described in this paper, California is using a novel approach for HD I/M program design intended to minimize burden on the regulated industry. We recommend coordinating with other states, including California, to gather information on best practices and lessons learned in developing an I/M program. Information regarding a program design tailored for the unique differences within the heavy-duty industry can be of great benefit during program development.

6. Acknowledgments

This report was prepared by Michael Sabisch, Jim Lindner, John Koupal, and Sandeep Kishan of ERG. The authors gratefully acknowledge the sponsorship of the OTC for this work, under the project leadership of Coralie Cooper; and valuable review and comments from Jim Clyne (NY), Madeline Haines (RI), Sonya Lewis-Cheatham (VA), Sharon Weber (MA), and Craig Woleader (MA).

7. Appendix A: Summary Matrix of OTC I/M Programs

Medium- and Heavy-Duty

State	Model Years	Regularity	Roadside?	Pre-OBD/type of check	OBD check?	Gas Vehicles?	Weights/classes included (GVWR lbs.)
CT	All weight class eligible greater than 4y and less than 25y	Biannual	Opacity	Gas Cap	Yes	Yes	8,501-10,000
DE	-	-	-	-	-	-	-
DC	1968+	Annual, except School Buses every 6 months	No	Idle Test	No	Gas only	< 26,000
ME	1996+	Annual	No	Gas Cap Pressure Test	Yes	Gas and diesel	<10,000
MD	1977+, newest 3 model years exempt	biennial	No	Idle and Gas Cap Test	Yes No	Gas only Gas only	<14,000 14,001-26,000
MA	1984-2013 2014+ (< 15 years for diesel) 2008+ (< 15 years)	Annual Annual Annual	No No No	Opacity Opacity for diesel No	No Planned Yes	No Gas and diesel Gas and diesel	>14,000 >14,000 8,501 – 14,000
NH	All diesel powered motor vehicles GVWR 10,000 lbs. or more and all diesel-powered buses manufactured to carry 25 or more passengers	Testing conducted as part of normal Dept. of Safety operations, either in conjunction with MCSAP inspections or other heavy duty vehicle enforcement duties	Yes	Opacity	No	No	All diesel powered motor vehicles GVWR 10,000 lbs. or more and all diesel-powered buses manufactured to carry 25 or more passengers
NJ	1996+ Gas 1997+ Diesel LDVs All 18000+ Diesels	Pass Vehicles – Biennial, Commercial Vehicles 1Yr, Buses every 6 months	Yes, both light and Heavy duty	N/A	Yes	All non-EVs Except Diesel 8501-17999lbs	All non-EVs Except Diesel 8501-17999lbs
NY	9-county NYMA HDDV I/M (No MY exemptions)	Annual	Yes (statewide	Opacity / Snap Acceleration	No	No	>8,500

State	Model Years	Regularity	Roadside?	Pre-OBD/type of check	OBD check?	Gas Vehicles?	Weights/classes included (GVWR lbs.)
	Statewide NYVIP, OBD and low enhanced (MD gas only), 2 MY old exemption, 25MY old exemption	Annual	diesel) Yes (statewide diesel)	ECD checks (MD gas only)	No	Yes, gas and diesel	8,500 < x <18,000
PA	1996+	Annual	No	Two-speed Idle, gas cap	Yes, 17 counties	Yes, gas only	8,500 lb - 9,000 lb
RI (*in dev., not final*)	All	Biennial	No	Vehicles that are not OBD-equipped shall be tested using the snap-acceleration test (SAE J1667).	Yes.	Diesel only	Vehicles > than 8,500 lbs. GVWR
VT	-	-	-	-	-	-	-
VA	-	-	-	-	-	-	-

Light-Duty Vehicles

State	Pre-OBD?	Centralized?	Model Years	Regularity	Visual Catalyst Check?	Diesel?	Other Notes
CT		No	Up to 25 years old, <5 exempt	Biennial	Yes		
DE	Yes (MY1968 -1980 Idle Test, MY1981-1995 Two speed Idle in New Castle and Kent County & MY1968 -2012 in Sussex County)	Yes	1968+, <5 exempt	Biennial	Yes	Yes	Annual Remote Sensing
DC	Yes (Idle < MY84, IM240 MY84-95)	Yes	1968+, <5 exempt	Biennial	Yes	No	
ME	Gas Cap Pressure Test	No	1974+	Annual	Yes	Yes	
MD	No	Yes	1996+, ≤3 exempt	Biennial	Yes	No	
MA		No	≥15 years exempt	Annual	No	Yes, ≥15 years exempt	

State	Pre-OBD?	Centralized?	Model Years	Regularity	Visual Catalyst Check?	Diesel?	Other Notes
NH	No	No	> 20 years exempt	Annual	No	Yes	
NJ		Yes*	<5 exempt	Biennial	Yes		
NY	Safety-only	Generally No, See Note	2-25 years old	Annual	Yes	Yes	Statewide NYVIP; NYC Taxi and Limousine Commission also operates a centralized, test-only, light-duty OBD program.
PA		No	1975+	Annual	Yes		
RI		No	2-25 years old	Biennial	No	Yes	Motor vehicles 25 years old or older must undergo inspection for safety and emissions (non-OBD subject to Visual Emission Component Test). However, these vehicles will not be failed if they do not pass emissions standards. The DMV grants diagnostic waivers as needed if the owners emission controls are in place and operational and there are no needed repairs.
VT	No	No	1968+ visual 16 MY + newer OBD	Annual	Yes	Yes	
VA		No	4-24 years old	Biennial	Yes	Yes (1997 and newer up to 8,500 lbs)	