Appendix G

Heavy-Duty Inspection and Maintenance Program Pilot Report

Proposed Heavy-Duty Inspection and Maintenance Regulation

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Executive Summary

Since the passage of Senate Bill (SB) 210 in 2019, the California Air Resources Board (CARB or Board), in collaboration with other state agencies and participating stakeholders, vendors, and contractors, developed and implemented a pilot program demonstrating potential technologies and methods for use in California's future heavy-duty inspection and maintenance (HD I/M) program. Studies focused not only on potential vehicle compliance test mechanisms, but also potential enforcement screening and vehicle identification methods that could be incorporated into the program to effectively bring vehicles into the HD I/M program. Beyond simply testing each technology, CARB assessed how various technologies could potentially be integrated together to improve the overall effectiveness of the future HD I/M program.

Under a CARB-funded research contract (CARB contract 15RD022), the University of California, Riverside's Center for Environmental Research and Technology (CE-CERT) performed preliminary HD I/M research to assess potential program structures and make an overall recommendation for a future HD I/M program. To do this, CE-CERT performed a literature review of different inspection and maintenance programs around the globe and performed a small-scale vehicle repair study to assess the effectiveness of different testing options. Based on repair results from the study, CE-CERT concluded that a future HD I/M program could result in substantial oxides of nitrogen (NOx) emission reductions, reducing heavy-duty vehicle (HDV) in-use emissions by about 50 to 75 percent from current baselines. Furthermore, based on the literature search and testing that was conducted as part of the study, CE-CERT recommended an on-board diagnostic (OBD)-based program incorporating a remote sensing screening element as the most cost-effective structure for designing a future HD I/M program. CARB used these preliminary results as a springboard to engage stakeholders, vendors, and other state agencies in discussions related to the overall structure and design of a future HD I/M program and the development of a pilot program to further assess potential feasibility.

As part of the pilot efforts, CARB staff coordinated with Eastern Research Group (ERG) and participating vendors to conduct testing focused on the potential incorporation of OBD testing into a future HD I/M program. Prototype OBD testing devices provided by participating vendors were used in combination with commercially available products to gather OBD data from HD vehicles and assess potential compliance with a future HD I/M program. The pilot efforts demonstrated that OBD collection could be used as an effective vehicle compliance test and that the OBD data fields CARB staff has proposed to collect as part of the upcoming HD I/M regulatory proposal would be feasible for testing devices to collect. The success of this testing assessment effort and the use of these piloted devices provide strong indications that vendors would be able to develop devices that meet the data collection requirements of a future HD I/M program in order to assess program compliance. Furthermore, ERG also coordinated with HDV repair shops to assess potential repair costs that could be associated with potential emissions control-related repairs in the future HD I/M program. ERG found average repair costs for OBD compliance issues to average slightly under $2,000 per repair. This cost data is used to help assess the economic impacts and cost-effectiveness of the future HD I/M program.

CARB also coordinated with the University of California, Irvine (UCI) Institute of Transportation Studies via an interagency agreement to conduct a pilot study relevant to the future use of Automated License Plate Recognition (ALPR) cameras and their potential use to monitor vehicle traffic into and out of the state. ALPR cameras were installed at multiple locations in Southern California to collect vehicle license plate information and assess the potential to use this technology as a method to help monitor for compliance with a future HD I/M program. This field pilot successfully tested that vehicle license plate data needed to cross-reference with vehicle compliance status to enforce on future non-compliant vehicles can be collected. Furthermore, the field testing provided valuable lessons to help optimize vehicle information collection rates for the future HD I/M program through improvements in camera positioning and software.

As part of efforts to improve enforcement of the future HD I/M program, CARB staff have internally been developing the **Portable Emissions Acquisitions System (**PEAQS) in association with ALPR systems over the past several years. These vehicle monitoring systems are envisioned to be used as potential screening tools for enforcement-related activities in the future HD I/M program. As part of these pilot efforts, CARB staff performed testing to demonstrate the capabilities of PEAQS and ALPR installments, which could be set up at various locations throughout the state to establish a statewide screening network for vehicles operating with high emissions. These pilot efforts tested the PEAQS systems in the field and assessed the feasibility of an unmanned permanently installed PEAQS network, along with manned mobile PEAQS units that can be moved to various locations throughout the state based on program needs. These pilot efforts helped staff uncover many ways to improve on the current PEAQS system to help ensure a robust design and application upon the implementation of the proposed HD I/M program. As examples, improvements made based on the results of these field testing efforts led to improvements in the durability of the overall system, improved detection of Transport Refrigeration Unit (TRU) activity, and an increase in vehicle capture rates. Overall, the pilot efforts demonstrated that PEAQS systems could effectively be installed both at unattended, semi-permanent locations and as mobile units to target potential non-compliant hot spots.

Pilot efforts also included a two-week pilot campaign in November 2020 performed in coordination with the California Department of Food and Agriculture (CDFA) and participating vendors near Mountain Pass, California. Various vehicle emissions testing systems were piloted to better understand how vehicle compliance tests such as OBD testing and opacity testing could work in collaboration with enforcement screening technologies. Multiple roadside emissions monitoring device (REMD) systems (including CARB's in-house PEAQS, as well as systems developed by two vendors, HEAT and OPUS) screened vehicles for emissions. Then, CARB staff used a subset of screened vehicles to further evaluate the systems in relation to potential vehicle compliance testing methods, e.g. OBD and opacity testing. Over ten thousand HDVs went through REMD test instrumentation, and over a hundred of these vehicles were subjected to the OBD and opacity testing over the two-week period. Results from the Mountain Pass pilot suggested that the three REMD systems can effectively be used as screening tools within the HD I/M construct. All three systems demonstrated effectiveness as stand-alone screening systems, meaning they could all be incorporated into a future HD I/M screening network. Thus, the future HD I/M program could incorporate REMDs as a screening tool. A vehicle identified by a REMD system as potentially having an emissions issue could be flagged for a follow-up compliance determination test such as an OBD test or opacity test to determine if the vehicle has a malfunctioning emissions control system and needs repair.

Another effort discussed in this report includes a one million dollar grant program conducted by CARB and the San Joaquin Valley Air District to assess the potential for a repair assistance program associated with the future HD I/M program. Approximately 150 vehicles were repaired at three repair shops in the San Joaquin Valley in the project. Although vehicles were successfully repaired, the project highlighted several challenges that would exist in setting up such a heavy-duty repair assistance program statewide. Finally, CARB undertook an internal repair study to assess the feasibility of repairing vehicles with severely malfunctioning aftertreatment. This study looked at the ability to effectively repair these vehicles, the emissions benefits that could be associated with these repairs, and the potential durability of the repairs. This was done through pre- and post-repair emissions measurements, followed by releasing these vehicles back into operation, and then procuring them again for follow-up emissions testing. This internal repair study showed that such vehicles could be repaired effectively resulting in substantial emissions benefits and durable repairs.

The table below summarizes the main conclusions of each of the studies laid out in this report. Chapter one lays out the initial background of why this report was conducted, then the subsequent chapters cover each of the studies discussed above.

STUDY (CHPT. #)	CONCLUSIONS
PRE-PILOT HD I/M STUDY (2)	• Repairs reduced NOx by 50 to over 75 percent. • Repairs cost $250 to $8,660; average cost was $2,037. • Program Design Recommendation: Periodic OBD data collection w/roadside emissions monitoring. • Chassis dynamometer, Portable Emissions Measurement System (PEMS) are not recommended for statewide vehicle compliance testing.

STUDY (CHPT. #)	CONCLUSIONS
OBD TESTING (3)	• Acquisition of OBD data being considered for the I/M program with two commercially available scan devices was demonstrated. • OBD data needed as part of an HD I/M program can reliably be acquired from current testing instrumentation. • OBD scans are quick to complete with an average duration of a couple of minutes. • The future HD I/M program could use either continuously connected or non-continuously connected scan devices.
ALPR FOR OUT-OF-STATE TRUCKS ENTERING CALIFORNIA (4)	• ALPR systems successfully collected license plate data from heavy-duty trucks with capture rates of 74 to 77 percent. • Lessons learned included: Certain types of plates are more difficult to recognize than others due to differences in their reflectivity. Roadside power can be inconsistent in some locations. Certain times of day present challenges due to different light conditions. Camera positioning and software calibration are key. Collaboration with external agencies may require encroachment permits or a memorandum of understanding. Some vehicles are missing their front license plates and will therefore be missed by ALPR systems.

STUDY (CHPT. #)	CONCLUSIONS
REMDS (5)	• PEAQS units are durable and reliable for long-term permanent use. • Recent improvements to the ALPR system have increased plate capture rate from 80 to above 90 percent. • New methods are needed that can distinguish TRU and tailpipe exhaust. • Future updates to PEAQS units based on lessons learned from these pilot efforts will improve detection capabilities. • Over 10,000 vehicle emissions data points were collected from vehicles travelling through participating REMD systems. • Three emissions monitoring systems were demonstrated as potential screening tools. • Over 100 OBD and opacity tests were obtained from vehicles participating in the campaign. • NOx emitted by HDVs measured on more than one day was similar. • Collected OBD data suggests vehicles operating with illuminated MILs have been travelling for a significant amount of time in a malmaintained state (over 100 hours of engine run-time, and over 5,000 kilometers traveled).
REPAIR ASSISTANCE (6)	• A $1 million program in the San Joaquin Valley performed 156 repairs. • To scale up to the state level, contracting difficulties would need to be overcome, and a streamlined system to determine eligibility would be needed. • It is unclear if such a program would be a good use of State funds given the Governor's direction to transform the state including trucking to zero-emission technologies
REPAIR DURABILITY (7)	• A CARB program repaired seven HDVs, reducing PM and/or NOx emissions by at least 55 percent. • HDVs with severely malfunctioning aftertreatment were repaired and their emissions were reduced dramatically. • Three HDVs were recaptured one month to three years after initial repairs; these repairs were found to be durable.

All in all, the efforts described herein helped demonstrate and fine-tune the use of technologies that may be used within the California HD I/M program. Furthermore, these efforts helped confirm the feasibility of rolling out an OBD based HD I/M program with a complementary REMD enforcement screening component. Further coordination and technological development will continue to ensure an effective rollout of the program.

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List of Acronyms and Other Abbreviations

ALPR	Automated License Plate Recognition
APCD	Air Pollution Control District
BAR	Bureau of Automotive Repair
BC	Black Carbon
CARB	California Air Resources Board
CE-CERT	Center for Environmental Research and Technology
CDFA	California Department of Food and Agriculture
CHP	California Highway Patrol
DEF	Diesel Exhaust Fluid
DM	Diagnostic Message
DMV	Department of Motor Vehicles
DPF	Diesel Particulate Filter
DTC	Diagnostic Trouble Code
EF	Emission Factor
EGR	Exhaust Gas Recirculation
ELD	Electronic Logging Device
GVWR	Gross Vehicle Weight Rating
HD I/M	Heavy-Duty Inspection and Maintenance
HDV	Heavy-Duty Vehicle
HDVIP	Heavy-Duty Vehicle Inspection Program
HDVRP	Heavy-Duty Vehicle Repair Program
IR	Infrared
MIL	Malfunction Indicator Lamp
MY	Model Year
NOx	$NO + NO_2$ (oxides of nitrogen)
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
PEAQS	Portable Emissions AcQuisition System
PEMS	Portable Emissions Measurement System
PGN	Parameter Group Number
PID	Parameter ID
PM	Particulate Matter
PSIP	Periodic Smoke Inspection Program
QA/QC	Quality Assurance / Quality Control
REMES	Roadside Emissions Monitoring and Enforcement System
REMD	Roadside Emissions Measurement Device
ROBD	Remote On-Board Diagnostic
RSD	Remote Sensing Device
SAE	Society of Automotive Engineers
SB 210	Senate Bill 210
SCR	Selective Catalytic Reduction
SPN	Suspect Parameter Number

TM&M	Tampering, Malfunction, & Mal-maintenance
TRU	Transport Refrigeration Unit
UCI	University of California, Irvine
UV	Ultraviolet
VDECS	Verified Diesel Emissions Control Strategy
VIN	Vehicle Identification Number

Chapter 1 Introduction and Background

California's Air Quality Issues and Need for Emissions Reductions

HDVs continue to be major contributors to statewide mobile air pollution even though this sector makes up only a small portion of California's total on-road vehicle fleet. In 2020, these vehicles emitted approximately 52 percent of the statewide on-road mobile source NOx emissions and about 54 percent of the statewide on-road mobile source fine particulate matter ($PM_{2.5}$) emissions (CARB, 2021a). HDVs' PM and NOx emissions impose a damaging effect on human health and the environment. In 1998, CARB identified PM from diesel-fueled engines as a carcinogenic toxic air contaminant due to its contribution to increased mortality, cancer risk, and serious illness (CARB, 2021b). NOx is a precursor of ozone formation and several other toxic air contaminants, including PM. Exposure to PM and ozone can lead to serious adverse health effects such as asthma, cardiopulmonary and respiratory diseases, and premature deaths. The majority of densely populated areas in California, such as the South Coast and San Joaquin Valley air basins, are still not in attainment with the federal ozone and $PM_{2.5}$ standards (US EPA, 2021). Thus, it is critical for CARB and the State of California to continue to work on programs that substantially reduce emissions from the vehicle sector to reduce the impact of these harmful pollutants on the state's constituents.

Overall attainment strategies for meeting federal air quality attainment standards are defined through the State Implementation Plan (SIP) process, which considers emission reduction measures from all pollution sources, including mobile sources. Through SIPs for the South Coast and San Joaquin Valley regions, CARB and the respective air districts have committed to regional NOx and PM emissions reductions from all sectors, including emissions reductions from the HDV sector. The development of an improved HD I/M program to further reduce in-use HDV emissions is expected to play a critical role in helping California meet near-term federal attainment NOx and PM standards in the South Coast and San Joaquin Valley regions, as well as in achieving overall statewide clean air goals outlined in CARB's Mobile Source Strategy (CARB, 2020d). Specifically, a revamped HD I/M program is critical for further progressing to meet the federal 8-hour ozone attainment deadlines in the South Coast Air basin in 2023 and 2031, and to achieve PM reductions for the 2024 federal attainment deadline and $PM_{2.5}$ reductions for 2025 federal attainment deadlines in the San Joaquin Valley region.

Overview of California's Current Heavy-Duty Vehicle Inspection Programs

In an effort to limit excess emissions from in-use HDVs, CARB currently implements two in-use vehicle inspection programs, the Heavy-Duty Vehicle Inspection Program (HDVIP) and the Periodic Smoke Inspection Program (PSIP). In the early 1990s, CARB first adopted the roadside program, HDVIP, that allows CARB staff to inspect heavy-duty trucks and buses operating in California for excessive smoke, tampering, and engine certification label (ECL) compliance. These CARB inspections are typically performed at border crossings, California Highway Patrol (CHP) Commercial Vehicle Enforcement Facilities (more commonly known as "weigh stations"), fleet facilities, and other randomly selected roadside locations. Vehicle owners found in violation are subject to monetary penalties and required to provide proof of correction to clear violations.

To complement the roadside HDVIP, CARB also adopted the Periodic Smoke Inspection Program (PSIP). In PSIP, California-based fleet owners of two or more heavy-duty diesel vehicles are required to perform annual smoke opacity tests following the Society of Automotive Engineers (SAE) International J1667 testing procedure (SAE, 1996) and adhere to other program requirements, such as recordkeeping. CARB staff are also authorized to randomly audits fleets, review maintenance and inspection records, and test a representative sample of vehicles to enforce the PSIP regulation.

Upon initial implementation in the early 1990s, the smoke opacity limits for both HDVIP and PSIP were set at 40 percent for 1991 and newer MY heavy-duty diesel engines and 55 percent for pre-1991 MY heavy-duty diesel engines. These opacity limits remained unchanged until 2018 when the Board approved more stringent smoke opacity limits (CARB, 2018), lowering the opacity limits to 5 percent for DPF equipped vehicles. The 2018 regulatory amendments to the HDVIP and PSIP reflect improvements in engine design and the evolution of PM exhaust emission control technologies and diesel fuel composition that have occurred since the inception of HDVIP and PSIP. Beginning with the 2007 model year (MY), new heavy-duty diesel engines were required to meet a PM engine standard of 0.01 grams per brake horsepower-hour (g/bhp-hr), which resulted in the widespread use of diesel particulate filters (DPFs) to meet this new engine standard. Additionally, CARB in-use rules such as the Truck and Bus rule required the installation of CARB-verified aftermarket DPFs for many HDV equipped with 2006 and older MY engines.

Need for Further Program Improvements

The implementation of the 2018 PSIP and HDVIP amendments have improved the ability to identify vehicles with broken DPFs. However, because these programs rely on smoke opacity inspections, they are limited to controlling PM emissions, even though near-term NOx emissions reductions throughout California are critical to achieving our clean air goals, protecting public health, and meeting federal attainment standards.

The current new engine emission standards in place since the 2010 (MY) require modern diesel engines to use NOx aftertreatment systems, such as selective catalytic reduction (SCR) (CARB, 2019a). However, the current smoke opacity test method does not measure NOx and hence does not verify whether emissions control systems like the SCR are in good condition.

Furthermore, advanced OBD systems became implemented with the 2013 (MY) for diesel-fueled heavy-duty engines and are specifically designed for monitoring the complete emissions control system of in-use vehicles (CARB, 2021e). OBD works by identifying malfunctions in emissions-related components, illuminating the malfunction indicator light (MIL), and storing fault codes to assist repair technicians with identifying and repairing broken emissions control components and systems. As the current HDVIP and PSIP programs rely mainly on the smoke opacity test for emissions-related diagnosis, the programs are only able to identify and ensure repairs on a subset of emissions control-related issues on HD vehicles, leaving many vehicle emissions issues unchecked resulting in the potential for excess emissions. As discussed later in this report, studies suggest that about 12 percent of vehicles in California are operating with an illuminated MIL.

In addition, enforcement enhancements relative to CARB's current HDVIP/PSIP regulations would help ensure more vehicles readily meet program requirements. The HDVIP program relies on roadside inspections of vehicles operating in California; however, due to limited CARB enforcement resources, HDVIP roadside inspections are only performed on about two percent of the total vehicle population operating on California roads per year. The PSIP program relies on CARB enforcement teams auditing fleets with annual smoke inspections; however, limited enforcement resources also hinder CARB's ability to effectively perform enough audits to ensure all fleets are meeting the PSIP requirements. This, in combination with the reliance on smoke opacity tests for vehicles with more advanced emissions detection systems, has resulted in more vehicles operating in California with excessive emissions than desired.

Senate Bill 210

Recognizing that a revamped and robust HD I/M program could provide significant and critically needed NOx and PM reductions, Senator Connie Leyva introduced SB 210 (Leyva; Chapter 298, Statutes of 2019) to direct CARB, in consultation with its partner State agencies, to develop a new, comprehensive HD I/M program applicable to non-gasoline HDVs operating in California with a gross vehicle weight rating (GVWR) above 14,000 pounds. SB 210 was signed into law by Governor Newsom on September 20, 2019. SB 210 specifically authorizes key general HD I/M program elements, including:

- HD I/M Test procedures that include, but are not limited to, the use of OBD data;
- Requirements for California-registered vehicles to pass the HD I/M test procedures, to be defined in the regulation, in order to register with the Department of Motor Vehicles (DMV) and operate in California;
- Requirements for all HDVs[1] to demonstrate compliance with the HD I/M requirements, pay a compliance fee, and obtain a valid compliance certificate to legally operate in California; and
- Statutory authority for CHP to cite vehicle owners for:
    - Invalid compliance certificate or lack of a valid compliance certificate;
    - Operating with an illuminated MIL; and
    - Operating with visible smoke opacity.

In doing so, SB 210 provides the opportunity to gain significant emission reductions beyond CARB's current vehicle inspection programs.

SB 210 also includes requirements specific to conducting HD I/M pilot program activities ahead of the Board's consideration of the proposed HD I/M regulation and its implementation. The bill states that CARB must conduct a pilot program in consultation with other state agencies to develop and demonstrate technologies that show potential for

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[1] As per SB 210 requirements, this includes nearly all non-gasoline vehicles over 14,000 pounds GVWR, including out-of-state and out-of-country vehicles.

readily bringing vehicles into the program. SB210 requires the findings of the pilot program to be posted on CARB's internet website.

Public Engagement for SB 210 Pilot Program Activities

As specified in SB 210, the pilot program should "develop and demonstrate technologies that show potential for readily bringing vehicles into the program." SB210 directs CARB to work in consultation with State agency partners and stakeholders as part of a public process. In 2019, CARB staff conducted an initial public workshop to discuss the need for an HD I/M program and to solicit other ideas for reducing emissions from in-use HDVs operating in California. Three subsequent workgroup meetings were conducted to further explore concepts for reducing in-use HDV emissions. After the passage of SB 210 in late 2019, CARB staff conducted four public workshops and six public workgroup meetings. These workshops and meetings focused on developing an effective HD I/M program structure and creating a pilot program to test compliance and enforcement strategies that could be incorporated into HD I/M. The public workshops were aimed at a broad cross-section of interested stakeholders and members of the public. They included representatives of heavy-duty fleets, trucking associations, engine/vehicle/device manufacturers, non-governmental organizations, and vehicle inspection and maintenance administrators in other states and countries. These meetings helped staff discuss and exchange ideas with interested stakeholders regarding the potential design of the HD I/M program and to delve into more technical details of specific program elements and potential pilot program activities.

CARB staff has also frequently met individually with interested stakeholders and organizations to further discuss the SB 210 pilot program development and overall program design. These stakeholders included representatives of trucking associations, agricultural trade associations, environmental groups, telematics service providers, OBD device vendors, and vehicle inspection and maintenance program representations from other states, among others. As directed by SB 210, CARB staff also regularly coordinated with the Bureau of Automotive Repair (BAR), DMV CHP, Department of Transportation (CalTrans), and the California Department of Food and Agriculture (CDFA) on the development of the HD I/M program and related pilot program activities, and will continue to do so when HD I/M program implementation begins.

Dates when public workshops and workgroup meetings were held are shown below (Table 1-1Table 1-2). Areas of expertise of State agency partners where coordination between CARB and the other agencies was focused are also summarized below in Table 1-3. Workshops and workgroup meetings shown in bold italicized text were specifically focused on SB 210 pilot program development and progress updates. Starting with the July 9, 2020, workgroup meeting, all workshops, workgroup meetings, and meetings with individual stakeholders, including State agency partners, were conducted via teleconference and/or webinar in accordance with Governor Newsom's Executive Orders *N-29-20* and *N-33-20*, as well as in accordance with recommendations from the California Department of Public Health.

Table 1-1. 2019 HD I/M Public Workshops and Workgroup Meetings (before the passage of SB 210).

DATE	EVENT
FEBRUARY 11, 2019	Workshop
MAY 14, 2019	Workgroup Meeting
JULY 16, 2019	Workgroup Meeting
NOVEMBER 8, 2019	Workgroup Meeting

Table 1-2. 2020 and 2021 HD I/M Public Workshops and Workgroup Meetings (after the passage of SB 210). Four public meetings focused on the pilot activities, highlighted in bold text.

DATE	EVENT
JANUARY 29, 2020	***Workshop to discuss SB 210 pilot program concepts and solicit additional stakeholder concepts***
FEBRUARY 19, 2020	***Workgroup meeting to continue potential pilot program concepts***
JULY 9, 2020	Workgroup Meeting
AUGUST 12, 2020	Workshop
NOVEMBER 16, 2020	***Workgroup meeting to discuss pilot program activities and progress updates***
DECEMBER 17, 2020	Workgroup Meeting
FEBRUARY 22, 2021	Workgroup Meeting

MARCH 29, 2021	Workgroup Meeting
MAY 27, 2021	Workshop
AUGUST 3, 2021	***Workshop to discuss SB 210 pilot program efforts and revised draft regulatory text***

Table 1-3. Coordination with State Agency Partners on SB 210 Pilot Activities.

STATE AGENCY	COORDINATION ROLE
BUREAU OF AUTOMOTIVE REPAIR	Expert consultant on I/M implementation, OBD data collection devices, and OBD data collection device certification
DEPARTMENT OF MOTOR VEHICLES	Vehicle data exchange process and California vehicle registration hold process of HD I/M non-compliant vehicles
CALIFORNIA HIGHWAY PATROL	Enforcement strategies coordination, installation of REMD at CHP sites
CALIFORNIA DEPARTMENT OF TRANSPORTATION	Assistance with site determination and installation of emissions monitoring equipment and ALPR camera, roadside siting and permitting
CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE	Assistance and coordination with equipment installation at CDFA agricultural inspection stations for pilot activities and future program efforts

SB 210 Pilot Effort

CARB staff and stakeholders used the guiding framework from SB 210 to develop the HD I/M pilot program. The pilot program encompassed multiple activities to holistically evaluate strategies and technologies for potential use in the HD I/M program. Strategies and technologies were aimed at enhancing vehicle participation in the program, assisting overall compliance efforts, and establishing effective enforcement mechanisms.

As meetings were held to discuss the potential design of the pilot program, some stakeholders suggested implementing the fully proposed HD I/M program for a short time, potentially in just one region of the state, as the pilot program itself. However, after further discussions on this topic, for the three reasons described further below, staff concluded such a full program pilot would not be consistent with the SB210 legislative intent or feasible.[2]

First, SB210 requires the pilot work to be completed prior to staff taking a regulatory proposal to their Board for consideration. The full HD I/M program will require a database system that receives vehicle data and test results and issues certificates of compliance and is connected with DMV registration. That database system cannot be fully completed until staff proposes and CARB approves the regulation, staff completes the State of California Project Approval Lifecycle process, and CARB's contractor builds, deploys the database system, and then connects it with DMV's vehicle registration system. Due to the need to complete the aforementioned steps, it would not be possible to perform a full program pilot and still meet the SB210 requirement for the pilot to be complete before the program is proposed to the Board.

Second, SB210 explicitly mentions testing "technologies that show potential," indicating the authors of the language recognized the value of testing individual technologies that could be included as part of a future program, rather than building out the entire program before performing a pilot of the whole. SB210 states: "This bill would require the state board, in consultation with the bureau and other specified entities, to implement a pilot program that develops and demonstrates technologies that show potential for readily bringing heavy-duty vehicles into an inspection and maintenance program…" In fact, when SB210 was being considered by the Legislature, the bill sponsor, Senator Connie Leyva, shared handouts with legislative staff specifically describing the pilot program as consisting of demonstrations of individual test devices that collect and submit OBD data (Office of Senator Connie Leyva, 2019).

Third, on January 26, 2021, Senator Connie Leyva sent CARB a letter expressing concerns with the program not being implemented until 2023 (Leyva, 2021). However, if Senator Leyva had envisioned the hiring of an implementation contractor and full database development prior to the pilot work, all before Board consideration of the regulation, she never would have sent a letter urging implementation in 2023. Under such a sequence of steps, the pilot program would realistically not be completed prior to 2023, pushing Board

[2] "No later than two years after the completion of the pilot program required by Section 44156 and to the extent authorized by federal law, the state board, in consultation with the bureau and the Department of Motor Vehicles, shall adopt and implement a regulation for a Heavy-Duty Vehicle Inspection and Maintenance Program…"

consideration to 2024, and program implementation out no earlier until 2025. Considering the urgency that Senator Leyva expressed regarding the timing of this HD I/M program and the timing of upcoming federal attainment deadlines, it is clear that Senator Leyva envisioned piloting of individual technologies which could be completed on a more rapid timescale.

Based on the rationale described above, CARB staff designed and implemented a pilot program that demonstrated technologies both for compliance determination and for catching vehicles trying to skirt the requirements of the program. The latter enforcement-related technologies are expected to enhance compliance rates with the program, thus bringing more vehicles into the program. Knowing that testing beyond this pilot program is important to ensure a smooth and robust rollout of the HD I/M program, CARB staff plans to further test each program component prior to rolling out each implementation phase of the proposed HD I/M program.

Performing the pilot program prior to officially proposing and implementing the HD I/M program helps to ensure the official program incorporates lessons learned from the pilot into the final design. It will also help ensure HD I/M is rolled out smoothly for stakeholders, and that the program design achieves maximum emissions reductions from the HD vehicle sector. For the purposes of this report and ease of reading, the pilot program description is broken up into separate chapters focusing on various technologies with the potential to bring vehicles into the program and ensure they are compliant with program requirements. This report breaks down the overall pilot program into the following chapters:

- **Chapter 2: Establishing the Feasibility of an HD I/M Program in California**
- **Chapter 3: OBD Testing Assessment**
- Chapter 4: **Monitoring Vehicles Coming Into California Using Automated License Plate Recognition (ALPR) Cameras**
- **Chapter 5: Remote Emissions Monitoring Devices to Support HD I/M**
- **Chapter 6: San Joaquin Valley Pilot Repair Assistance Effort**
- **Chapter 7: CARB In-House Heavy-Duty Vehicle Repair Durability Study**
- **Supplemental Chapter A: Final Report, Heavy-duty On-Road Vehicle Inspection and Maintenance Program, CARB Contract No. 15RD022**
- **Supplemental Chapter B: Final Report, Heavy-Duty On-Board Diagnostic Data Collection Demonstration and Repair Data Collection Study, CARB Contract No. 18MSC001**

- **Supplemental Chapter C: Heavy-Duty Vehicle Repair Program Pilot Project, Final Report**
- **Supplemental Chapter D: Additional Information on CARB Repair Durability Study**

Chapter 2 focuses on HD I/M development efforts that were undertaken prior to the official SB 210 HD I/M pilot effort. Chapters 3 through 5 focus on specific activities done as part of the SB210 pilot. Chapters 6 and 7, although not part of the official SB210 pilot effort, are included in this report for completeness as the efforts related to the repair assistance studies and repairs are relevant to the development of the HD I/M program as a whole.

Chapter 2 Establishing the Technical Feasibility of an HD I/M Program in California

Recognizing the potential need for a new, comprehensive inspection and maintenance program for HDVs operating in California, CARB dedicated research funding to evaluate the technical feasibility of such a program and whether significant emission reductions, particularly NOx reductions, could be achieved to further California's progress in attaining federal air quality standards and CARB's overall clean air, sustainable freight, and climate goals. CARB ultimately awarded a contract to CE-CERT at the University of California at Riverside. This CE-CERT study, published in January 2019, assessed various HDV test methods and laid the foundation for further HD I/M-related studies and technology demonstrations conducted as part of the SB 210 pilot program activities. Here we summarize the project at a high level and highlight the key findings that helped lay the foundation for initial program design and pilot discussions with stakeholders. Full details of this research effort are included in the final CE-CERT report incorporated into this pilot report as Supplemental Chapter A.

Study Objectives and Methodology

CE-CERT study developed, evaluated, and assessed compliance testing options for a more comprehensive HD I/M program for vehicles over 14,000 pounds GVWR. Furthermore, recommendations for the potential design and implementation of a full-scale HD I/M program were made based on the results of the study. CE-CERT's efforts included a literature review of potential inspection and maintenance test procedures that could be incorporated into an HD I/M program, and implementation of a small-scale research prototype to assess potential feasibility in a future HD I/M program.

Based on the literature review, the study determined that the following potential methodologies and emissions testing instrumentation would be evaluated in the small-scale research prototype:

- Repair grade chassis dynamometer with NOx and PM I/M grade emissions analyzers;
- Mini-portable emissions measurement systems (PEMS), called mini-PEMS (sensor-based and solid particle number based);
- Remote emissions monitoring devices;
- OBD data collection; and
- Smoke opacity inspections.

The small-scale research prototype measured pre- and post-repair emissions from 50 vehicles with a variety of emissions testing instrumentation identified above, including the Hager Environmental and Atmospheric Technologies' Emissions Detecting and Reporting (EDAR) remote sensing device (RSD) and CARB's plume capture system, Portable Emissions Acquisions System (PEAQS).

CE-CERT selected candidate vehicles for evaluation in the small-scale research prototype from those arriving at two southern California repair facilities based on whether they fell into specific MY engine ranges and the type of emissions-related malfunction. The vehicle selection process looked to mimic a vehicle distribution similar to what we expect to find on California roads in the mid-2020s with probable emissions-related issues expected of such vehicles. The final selected test fleet was composed of 20 percent of vehicles with pre-OBD engines (2010 – 2012 MY engines) and 80 percent with OBD-equipped engines (2013 and newer MY engines).

CE-CERT also developed a target repair test matrix for the selected vehicles, which contained component or systems malfunctions expected to cause excessive emissions of different pollutants. The target test matrix was developed using the best available data and historical repair records obtained from participating repair shops to estimate the frequency at which identified repairs were expected to occur. This effort was coupled with estimates of the expected emissions increases from the various component or system failures, based on CARB's on-road emissions inventory model, EMFAC, at the time of the study.

Study Results and Recommendations

Based on the results of the small-scale prototype HD I/M program, CE-CERT recommended a tiered approach of testing options that could be implemented separately or in combination with each other for a cost-effective HD I/M program. CE-CERT's overarching recommendation was that the most effective HD I/M program would combine OBD data collection with roadside emissions monitoring to cross-check the test methods and validate program effectiveness. Presented below are CE-CERT's major findings and recommendations from the project:

- <u>Estimated NOx reductions:</u> Results from the small-scale prototype HD I/M program conducted in this study indicate NOx emission reductions ranging from about 50 percent to over 75 percent could be achieved through appropriate vehicle diagnosis and repair.
- <u>Estimated repair costs:</u> Vehicle repair costs resulting from the small-scale prototype HD I/M program ranged from $250 to approximately $8,660, depending on the extent

of repairs needed. The costliest repairs were those associated with the replacement of major components, such as the DPF, SCR, turbocharger, or injector doser. Less expensive repairs included those that were sensor replacements or recalibrations. The costs associated with OBD-related repairs could span a relatively wide range, as OBD is designed to identify issues in emissions-related components before they become catastrophic failures. For vehicles with the MIL on, the average repair cost was $2,037 per vehicle. As a comparison, the estimated annual average cost of operating a heavy-duty vehicle above 14,000 lbs GVWR is about $41,000,[3] with annual costs potentially upwards of $162,000 for class 8 long haul vehicles that operate can operate 100,000 miles per year.

- Chassis dynamometer and 40 CFR 1065-compliant PEMS: The study considered chassis dynamometer and fully 40 CFR 1065-compliant PEMS testing methods for use in a statewide HD I/M program. However, these intensive test methods would require vehicles to report to a centralized location and to be taken out of service, thereby resulting in significant operational downtime for vehicle owners. Additionally, the greater capital costs associated with these test methods and the need for extensive testing networks significantly constrain their feasibility as cost-effective and unintrusive options for a statewide HD I/M program.

- OBD data collection as the primary testing option: OBD monitors all emissions critical components and related sensors while a vehicle is operating. An OBD-based test could be relatively quick and convenient for the owner/operator in comparison to other options, and the test costs and inspection time burdens to the owner can be considerably lower than chassis dynamometer or PEMS-based alternatives. The implementation of telematics could provide further benefits in terms of the ease of implementing an HD I/M program, either through kiosk systems or through cellular data transmission.

- OBD data collection coupled with roadside emissions monitoring: CE-CERT's next recommendation was to supplement OBD data collection with a roadside emissions monitoring component, using a REMD like PEAQS. These systems capture vehicle emissions as vehicles pass by the monitoring equipment to allow analyses of emissions levels generated during real-world driving conditions. Analyses of on-road emissions

[3] This is based on a per-mile cost of $1.62 for the western United States, taken from (ATRI, 2020) by the American Transportation Research Institute, and an average annual mileage accrual of 25,467 for HDVs above 14,000 GVWR. Annual mileage accrual is based on vehicle mileage accrual projections in CARB's EMFAC.

would allow CARB staff to assess how well the HD I/M program is working as a whole, and to work towards implementing program improvements, as necessary.

Study Application

CE-CERT study's recommendations served as a foundational starting point to engage stakeholders in developing an HD I/M program structure and establishing the SB 210 pilot program. Based on the outcomes of stakeholder engagement related to the development of the SB210 pilot efforts, the pilot was designed to further test and demonstrate the various elements that had strong potential to be incorporated into the future HD I/M program. Potential program elements and the interplay between elements such as OBD testing applications, remote sensing systems, and enforcement-related technologies such as license plate camera detection were further evaluated as part of this SB210 pilot.

Chapter 3 OBD Testing Assessment

Based on the success of OBD testing in light-duty vehicle I/M programs across the US, a similar OBD focused structure for the future HD I/M program was assessed as part of this pilot effort. Considering an OBD-centric I/M program has not been implemented yet in the HDV sector, a key goal of the pilot program was confirming that OBD data can reliably be collected from the HDV population and that testing devices can be adequately developed to meet the proposed data collection requirements. This chapter focuses on pilot demonstration efforts to assess the feasibility of OBD testing devices. Furthermore, this effort looks to assess the reliability of collecting the OBD data fields CARB is currently planning to collect under the proposed HD I/M regulation. This pilot effort was done in coordination with ERG, who was contracted to help support the OBD piloting efforts.

Beyond the OBD feasibility piloting efforts, OBD fault code and MIL data were collected from a sample of the HDV population to assess potential repairs that may be associated with common fault codes. This analysis was then cross-referenced with repair shop data to estimate potential costs of the associated repairs and used to assess the potential economic impacts of a future HD I/M program. Conclusions from this pilot effort indicate that the proposed HD I/M program's OBD data collection requirements are feasible and can be met by future testing devices. Additionally, OBD data and cost information collected as part of this pilot effort can be used to support economic impact assessments associated with the development of this program. Further details can be found in Supplemental Chapter B, the final report associated with the ERG contract with CARB.

OBD Data Collection Feasibility Demonstration

The OBD demonstration effort included voluntary participation from interested fleets. Testing device vendors either developed prototype testing devices in an effort to meet the proposed OBD data collection requirements or provided currently available testing devices that already have such capabilities. CARB and ERG worked with participating vendors, test organizations, and fleets to demonstrate the testing technology and assess the level of effort and time it may take to perform such OBD data collection efforts. In addition to OBD testing efforts, an HD I/M survey was conducted on heavy-duty fleets to gather information regarding heavy-duty industry preferences related to an OBD-based HD I/M program. The demonstration study findings helped evaluate the scalability of OBD testing and OBD data transmission methods that could be used for the proposed OBD testing requirements in the future statewide HD I/M program.

OBD Data Collection Demonstration

OBD Data Collection Tools

Participating vendors included Drew Technologies and HEM Data Corporation. Figure 3-1 shows the tested Drew Technologies' DrewLinQ device. The DrewLinQ device is a commercially available vehicle diagnostic adaptor that can be used to connect the vehicle's diagnostic port to data collection or diagnostic software. To support the OBD data collection demonstration, Drew Technologies developed a software application prototype to allow the DrewLinQ device to collect OBD data from HDVs through both SAE J1939 and J1979 communication protocols. Drew Technologies also updated the device to allow it to collect all the OBD data fields specified in Tables 3-1 and 3-2, thus allowing for the collection of CARB's proposed required OBD data parameters for the future OBD-based HD I/M program. The DrewLinQ device requires the use of a personal computer (PC) or tablet computer, and online activation of the device prior to usage. Six of the devices were used for the demonstration study.

Figure 3-1. DrewLinQ OBD Data Collection Device.

In addition to the DrewLinQ device, the OBD Mini Logger and DAWN Mini Streamer provided by HEM Data Corporation, as shown in Figure 3-2, were used to collect OBD data from a subset of participating vehicles. The OBD Mini Logger is a stand-alone configurable datalogger capable of collecting and logging data for both SAE J1939 and J1979 OBD data communication protocols, and can also serve as a telematics device. The Mini Streamer provides real-time streaming of SAE J1939 and J1979 data to a PC, Android device, or iOS-based tablet (iPad as shown in Figure 3-2) for the collection of vehicle service and performance data. Similar to the DrewLinQ device, the HEM Data devices are commercially available vehicle diagnostic tools. ERG prepared a configuration file to use with the Mini Logger in the pilot program, while no updated configuration was required for the Mini Streamer.

Figure 3-2. HEM OBD Mini Logger and DAWN Mini Streamer.

Table 3-1 and Table 3-2 below summarize CARB's proposed OBD data parameters for SAE J1939 and J1979, respectively.

Table 3-1. CARB's Proposed SAE J1939 Parameters.

MESSAGE	PARAMETER GROUP NUMBER (PGN)	DESCRIPTION
DM01	65226	Active Diagnostic Trouble Codes (DTC)
DM02	65227	Previous DTCs
DM04	65229	Freeze Frame Parameters
DM05	65230	Diagnostic Readiness 1
DM06	65231	Emissions-Related Pending DTCs
DM07	58112	Command Non-continuous Test
DM12	65236	Emissions Related Active DTCs
DM19	54016	Calibration Information (Calibration Identification (Cal ID) and Calibration Verification Number (CVN))
DM20	49664	Monitor Performance Ratio
DM21	49408	Diagnostic Readiness 2
DM23	64949	Previous Emission-Related DTCs
DM24	64950	Suspect Parameter Number (SPN) Support
DM25	64951	Expanded Freeze Frame
DM26	64952	Diagnostic Readiness 3
DM27	64898	Pending DTCs
DM28	64896	Permanent DTCs
DM29	40448	Regulated DTC Counts

MESSAGE	PARAMETER GROUP NUMBER (PGN)	DESCRIPTION
DM30	41984	Scaled Test Results
DM31	41728	DTC to Lamp Association
DM32	41472	Regulated Exhaust Emission Level Exceedance
DM33	41216	Emission Increasing Auxiliary Emission Control Device (AECD) Active Time
DM34	40960	Not-to-Exceed (NTE) Status
DM56	64711	Model Year and Certification Engine Family
VI	65260	Vehicle Identification Number (VIN)
CI	65269	Engine Serial Number (SPN 588)
AC	60928	Name of controller application
ET1	65262	Engine coolant temperature
CCVS1	65265	Wheel-based vehicle speed
IC1	65270	Intake manifold #1 pressure
IC1	65270	Intake manifold #1 temperature
EEC2	61443	Accelerator pedal position 1
EEC2	61443	Engine % load at current speed
EEC1	61444	Actual engine - % torque
EEC1	61444	Engine speed
EEC1	61444	Engine torque mode

MESSAGE	PARAMETER GROUP NUMBER (PGN)	DESCRIPTION
IT6	65159	Engine actual ignition timing
AT1S	64891	Aftertreatment 1 Diesel Particulate Filter (DPF) soot load %
ESR	34560	Engine Protection Derate Override Command
CTL	52992	Engine Torque Limit Request - Maximum Continuous
EBC1	61441	Engine Derate Switch
GC2	61470	Engine Self-Induced Derate Inhibit
EOI2	61711	Engine Self-Induced Derate Load
EOI	64914	Engine Derate Request
TTI1	65204	Trip Time in Derate by Engine

Table 3-2. CARB's Proposed SAE J1979 Parameters.

Mode	**Parameter Identification (PID)**	**Description**
1	01	Malfunction Indicator Light (MIL), DTC count, status of monitors
1	02	Freeze frame DTC
1	1C	OBD Requirements to which vehicle is designed
1	21	Distance Travelled While MIL is Activated
1	30	Number of Warm-ups Since DTC Cleared

Mode	**Parameter Identification (PID)**	**Description**
1	31	Distance since diagnostic trouble codes cleared
1	41	Monitor status (trip-based)
1	4D	Minutes Run with MIL Activated
1	4E	Time Since DTCs Were Cleared
1	A6	Odometer
1	all	All other live data PIDs
2	all	Freeze Frame Data
3	n/a	Stored DTCs
6	n/a	Test Mode
7	n/a	Pending DTCs
9	01, 02	Vehicle info, VIN
9	03, 04	Vehicle info, Cal ID
9	05, 06	Vehicle info, CVN
9	09, 0A	Engine Control Unit ID
9	0D	Engine Serial Number
0A	n/a	Permanent DTCs

Field OBD Data Collection

Due to the COVID pandemic and resulting travel restrictions, field-OBD data collection in California was limited (148 HDVs). As a result, field-OBD data collection was expanded to also be performed in other states such as Arizona, Colorado, and Texas (204 HDVs). Regardless of the testing location, all vehicles were certified to CARB's OBD certification standards, thus, the change in testing venue did not impact the pilot efforts or the resultant conclusions. In total, 352 HDVs were tested, including vehicles with both the SAE J1939 and J1979 OBD communication protocols. Figure 3-3 shows the distribution of tested HDVs by vehicle make. The majority of OBD data were collected from vehicles with the SAE J1939 OBD data communication protocol (about 90 percent of tested HDVs) due to the prevalence of these vehicles compared to vehicles with the SAE J1979 OBD data communication protocol in the heavy-duty sector. Approximately 75 percent of OBD-equipped HDVs in California are certified with the SAE J1939 OBD data communication protocol.

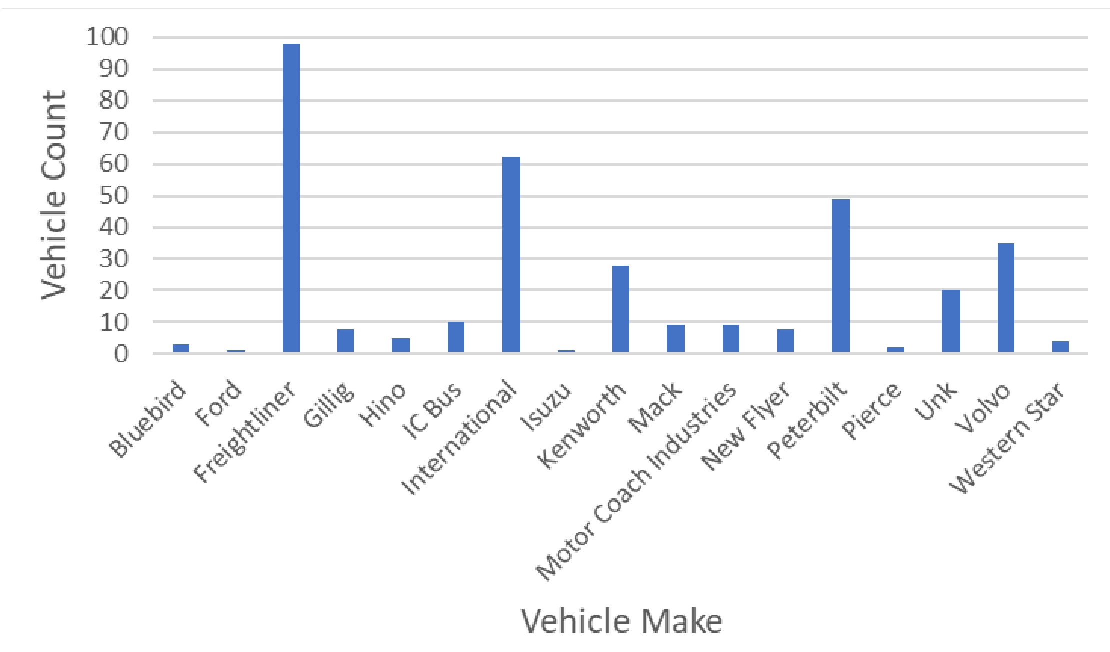


Figure 3-3. Distribution of vehicles tested by chassis original equipment manufacturer (OEM).

Figure 3-4 shows the OBD failure[4] rate distribution across the tested vehicle MYs. Although not sampled in a way to represent the distribution of the on-road fleet by age, the observed OBD failure rate trend suggested a significant percentage of newer vehicles are likely to fail an OBD test when the HD I/M program is first implemented. As shown, 12

[4] OBD failure criteria – vehicles that have MIL commanded on

percent of tested 2020 MY vehicles had MIL on. This 12 percent MIL-on rate is consistent with CARB's OBD field testing effort in 2018.[5]

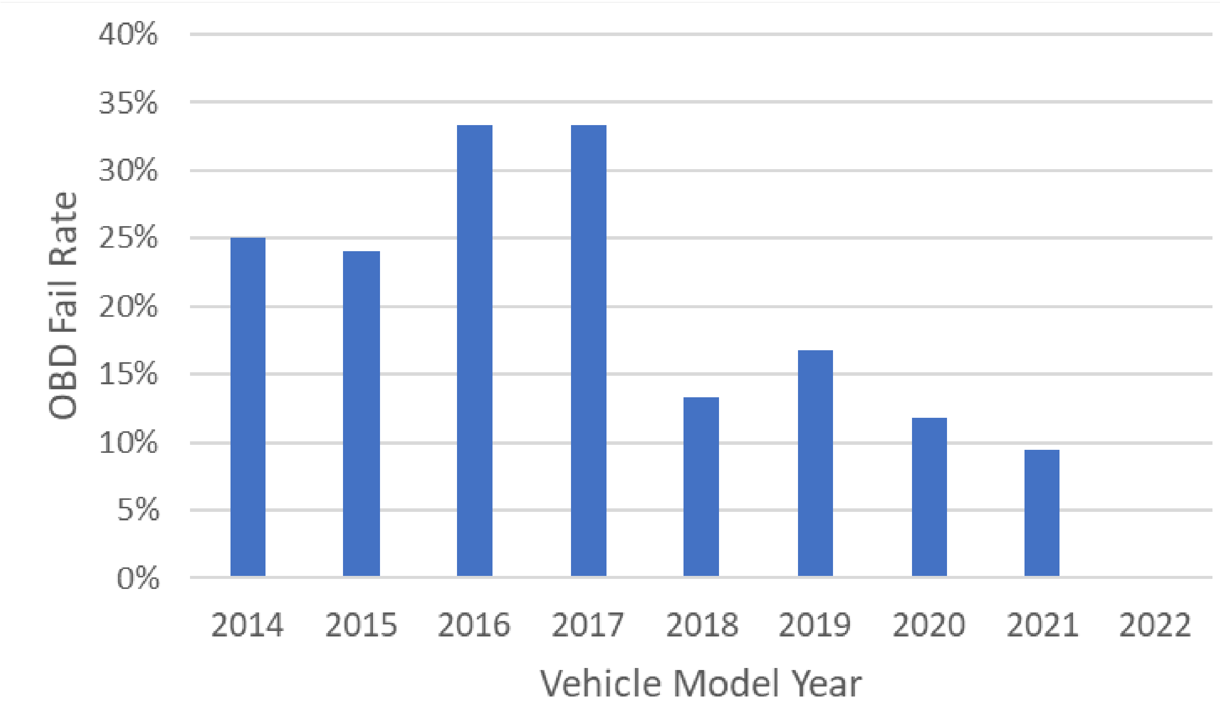


Figure 3-4. Tested Vehicle OBD Failure Rate Distribution by MY during the Field OBD-Data Collection.

Among the tested vehicles, the DrewLinQ devices were used for OBD data collection on 220 vehicles, the HEM devices were used for OBD data collection on 123 vehicles, and both DrewLinQ and HEM devices were used for OBD data collection concurrently on 9 vehicles. Albeit limited, the OBD data collected from both DrewLinQ and HEM devices were shown to be consistent with each other when tested on the same vehicles.

DrewLinQ Devices

Using the DrewLinQ devices, the average OBD testing duration for the vehicles with SAE J1939 OBD data communication protocol was about 3.5 minutes per OBD scan per vehicle; meanwhile, the average OBD testing duration for the vehicles with SAE J1979 OBD data communication protocol was significantly shorter, only 1.5 minutes.

For the vehicles tested with the SAE J1939 communication protocol, the DrewLinQ devices were able to successfully collect all CARB's proposed required SAE J1939 OBD data

[5] CARB's field OBD data collection in 2018 tested 213 randomly selected heavy-duty OBD-equipped vehicles at weight stations in Northern and Southern California.

parameters except DM30 (PGN 41984). At the time these testing and device development efforts occurred, DM30 was not included in CARB's provided data schema as part of the future HD I/M program. However, the vendor indicated that updates to the devices could be programmed in the future to collect such data as part of a full-scale HD I/M program. For vehicles equipped with the SAE J1979 communication protocol, the DrewLinQ devices were able to successfully collect all CARB's proposed required SAE J1979 OBD data parameters except the freeze frame data (Service $02). Due to time constraints on software programming related to the timing of the pilot deployments, the DrewLinQ devices were not programmed to collect freeze frame data. However, as with DM30 for the SAE J1939 protocol, the vendor indicated that device updates would be feasible to incorporate such data as part of the future full-scale program.

HEM Data Devices

As mentioned earlier, the HEM Data Mini Logger was programmed to automatically collect a pre-configured record of OBD data parameters from the vehicle OBD controllers. The HEM Data Mini Logger, as the device name implies, functions as a stand-alone data logger. As long as the device is plugged into the vehicle's OBD port, the device will continuously record and store the specified OBD data parameters from the vehicle at a specified rate. The HEM Data DAWN Mini Streamer functions in a similar manner to the DrewLinQ device to get a snapshot of the requested OBD data at the time the OBD test is performed. In general, the OBD data collection duration of the HEM Data devices was similar to the tested DrewLinQ devices.

As with the DrewLinQ, the HEM Data devices were able to collect all of CARB's proposed required SAE J1939 and J1979 OBD parameters except DM30 for SAE J1939 vehicles during the demonstration study. HEM recently reported that the HEM DAWN Mini Streamer can now acquire the DM30 parameter for SAE J1939 vehicles.

HD I/M Survey

As part of the pilot effort, a survey was conducted on heavy-duty fleets to gather information regarding industry preferences for a potential OBD-based HD I/M program. To help inform HD I/M program development, questions focused on topics related to preferences of potential OBD testing options that could be incorporated into the future program and current fleet usage of telematics and logistic services. The survey was conducted remotely via online, telephone, and email. In an effort to increase fleet participation, the survey was advertised through CARB's diesel truck information portal - The TruckStop website, as well as at CARB's One Stop training class. Furthermore, email notifications were sent out to CARB's HD I/M govdelivery subscribers and the survey was highlighted during HD I/M workgroup presentations. A summary of the results of the survey is discussed below, however, further details on the survey results and the specific questions that were asked in the survey can be found in Supplemental Chapter B as well.

In total, 37 heavy-duty fleets participated in the survey, among which 30 fleets participated via an online survey and 7 fleets participated via telephone/email survey. The number of respondents varies from question to question. Participating heavy-duty fleets in the survey vary in fleet size ranging from 1 vehicle to more than 50 vehicles with 30 percent (the highest) of the survey responses coming from single-vehicle fleets, as shown in Figure 3-5. Most of the participating fleets (63 percent) consisted mainly of in-state operation within a 100-mile radius from their domiciled base, as shown in Figure 3-6.

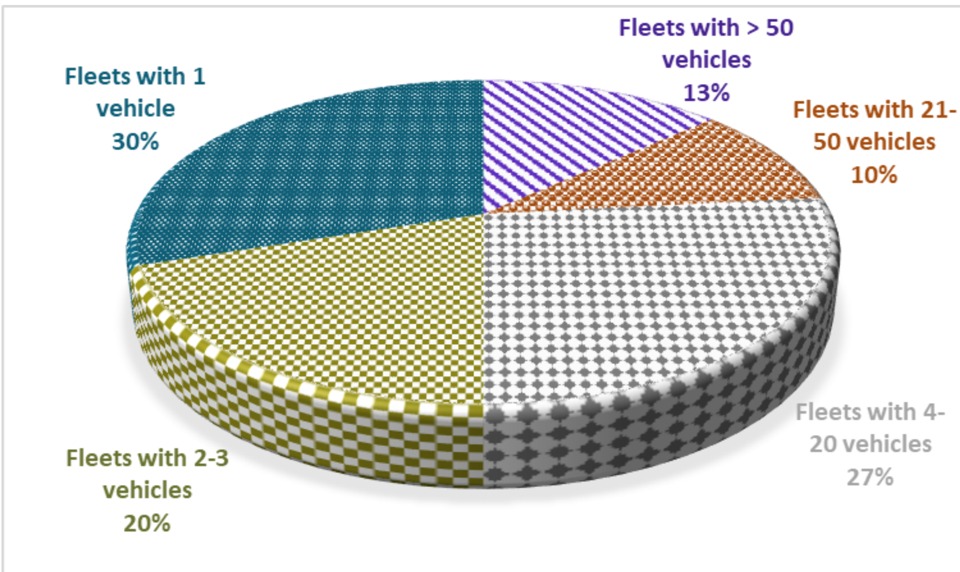


Figure 3-5. Fleet Size Distribution of Surveyed Heavy-Duty Fleets.

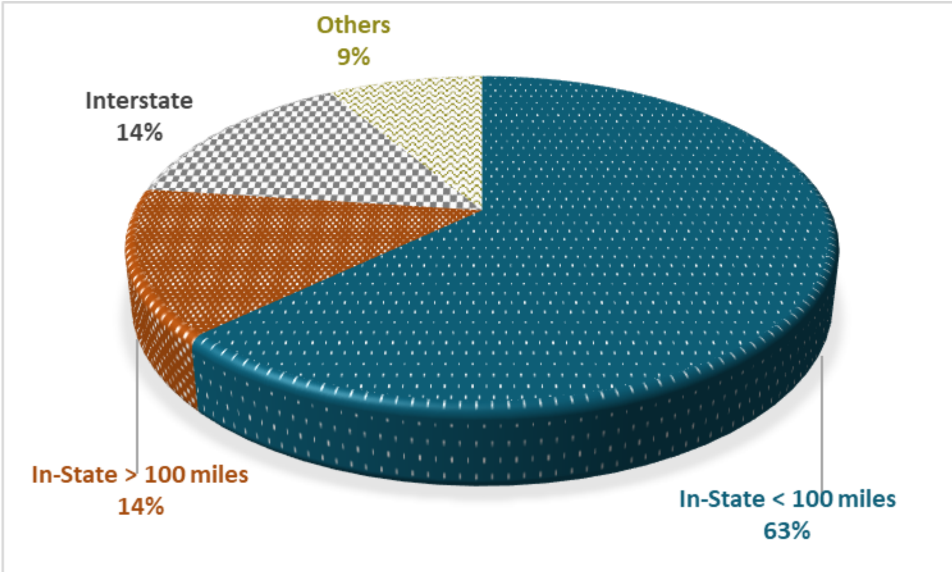


Figure 3-6. Fleet Service Type Distribution of Surveyed Heavy-Duty Fleets.

Regarding current heavy-duty fleet telematics practice, 43 percent of participating heavy-duty fleets responded they are currently using some forms of telematics services for fleet logistic management support, vehicle diagnostic and preventative maintenance support, and federal Electronic Logging Device (ELD) requirement support. Nearly all surveyed large fleets of more than 50 vehicles indicated they are using telematics (91 percent).

As part of the survey, heavy-duty fleets were queried about what OBD testing options they would prefer based on a quarterly periodic testing requirement. The OBD testing options described in the survey include:

- Fleet self-testing by kiosk: Visiting a physical testing location to self-perform required vehicle testing
- Fleet on-site testing by self or a third-party tester: Having a CARB-approved tester to perform required testing at a fleet yard or other convenient location, similar to trained testers for California's PSIP
- Telematics: Using a telematics service provider (OEM or aftermarket) to submit required compliance testing information

Forty-three percent of fleets selected the fleet on-site testing by self or a third-party tester, 37 percent of fleets selected telematics, and 20 percent of fleets selected fleet self-testing by kiosk, as shown in Figure 3-7.

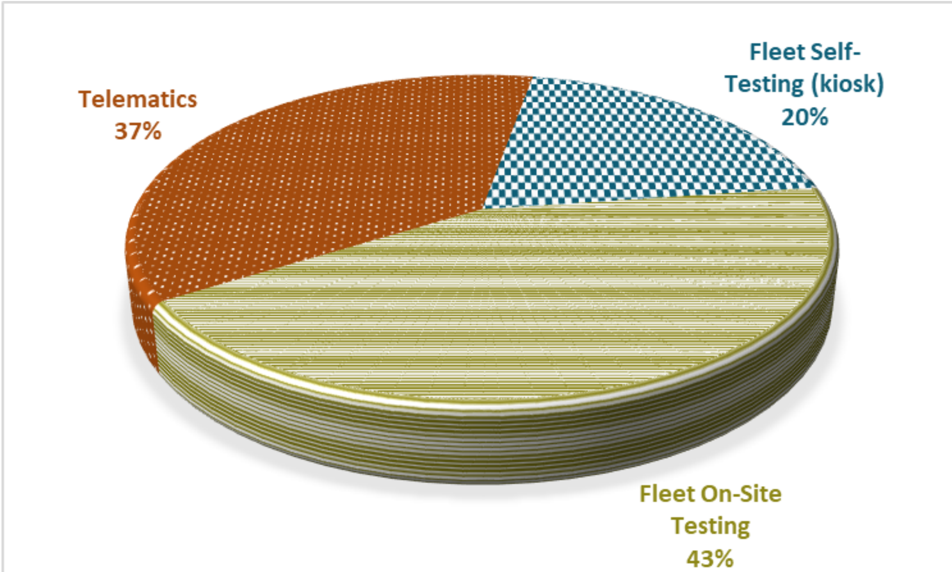


Figure 3-7. OBD Testing Preference Distribution of the Surveyed Heavy-Duty Fleets.

OBD-Related Repair Data Collection

As part of another CARB contract (ERG, 2020), ERG collected OBD fault codes for 180,000 heavy-duty OBD-equipped vehicles in the U.S. Using that data, and also fault code and repair data ERG collected in this pilot study, ERG, in coordination with sources in the HD repair industry, performed an analysis comparing OBD fault codes and associating them with related repairs and costs. The collected repair data and ERG's cost analysis supported CARB's assessment of the proposed HD I/M program repair cost analysis and potential economic impact on heavy-duty fleets due to the resulting OBD-related repairs expected to be necessary in order to comply with the upcoming HD I/M program.

From the OBD fault codes dataset, ERG identified 42 of the most commonly occurring OBD fault codes and categorized them into the following eight emissions-related groupings:

- Boost Control
- Exhaust Gas Recovery (EGR)
- Fuel System Monitoring
- NOx Sensor
- PM Filter
- PM Filter Frequent Regeneration
- Reductant Delivery
- SCR Catalyst

For each of the 42 common OBD fault codes, ERG identified the corresponding most likely repair(s) and their associated costs through commercially available repair resources and inputs from repair shops and organizations. Further details on how these determinations were made can be found in Supplemental Chapter B of this report. Table 3-3 summarizes the cost estimates for each grouping listed above by manufacturer.

Table 3-3. Average Repair Cost by Tampering, Malfunction, & Mal-maintenance (TM&M) Category by manufacturer.

TM&M CATEGORY	OEM 1	OEM 2	OEM 3	AVERAGE COSTS[6]
BOOST CONTROL	$2,623	$2,088	$2,123	**$2,278**
EGR	$1,202	$1,343	$2,092	**$1,546**
FUEL SYSTEM MONITORING	$1,598	$2,007	$1,931	**$1,848**
NOX SENSOR	$1,658	$1,849	$2,125	**$1,877**
PM FILTER	$2,606	$1,463	$2,742	**$2,305**
PM FILTER FREQUENT REGENERATION	$1,872	$1,511	$2,497	**$1,960**
REDUCTANT DELIVERY	$2,292	$1,855	$2,328	**$2,169**
SCR CATALYST	$1,490	$2,125	$1,837	**$1,817**

Table 3-4 summarizes the distribution of groupings based on their corresponding distribution of fault code counts. This was then weighted to determine an overall average repair cost for an OBD-related vehicle compliance test failure.

Table 3-4. Weighted Average OBD-Related Repair Cost per Vehicle Repair.

TM&M CATEGORY	TOTAL FAULT CODE COUNT	FAULT CODE DISTRIBUTION	REPAIR COSTS
BOOST CONTROL	5,905	10.85%	$2,278

[6] Average of all the repair costs in the corresponding TM&M category for all OEMs

TM&M CATEGORY	TOTAL FAULT CODE COUNT	FAULT CODE DISTRIBUTION	REPAIR COSTS
EGR	6,353	11.68%	$1,546
FUEL SYSTEM MONITORING	8,678	15.95%	$1,848
NOX SENSOR	8,085	14.86%	$1,877
PM FILTER	6,395	11.75%	$2,305
PM FILTER FREQUENT REGENERATION	862	1.58%	$1,960
REDUCTANT DELIVERY	10,583	19.45%	$2,169
SCR CATALYST	7,552	13.88%	$1,817
WEIGHTED AVERAGE COSTS PER VEHICLE REPAIR			**$1,977**

Based on these assumptions, an average cost of $1,977 per vehicle is estimated per repair for a potential OBD compliance failure as part of the future HD I/M program, similar to the repair costs projected from previous repair cost projections discussed previously in Chapter 2. This cost data will be used to support the economic analysis associated with the development of CARB's future HD I/M program.

Conclusions informing the structure of the future HD I/M Program

These OBD demonstration pilot efforts done in coordination with ERG successfully demonstrated that a future HD I/M program can use OBD testing as the focal point of determining vehicle compliance and that testing devices can be developed to support the program requirements. The results support the assessment that CARB's proposed HD I/M

OBD data collection requirements are feasible and that current OBD data collection technology can support CARB's proposed OBD testing requirements in a future HD I/M program. The tested DrewLinQ devices, as well as HEM Mini Logger and DAWN Mini Streamer, were shown to be able to reliably collect CARB's required OBD data parameters. These efforts also verified that the required OBD data is reliably available on HDVs and can be downloaded by testing devices when requested and that the OBD testing procedure can be performed quickly. The OBD testing duration for an OBD scan with the prototypes tested was demonstrated to be about 1.5 to 3.5 minutes on average.

Based on these results, CARB staff believes it is feasible to allow the use of two types of OBD devices as part of the future HD I/M program - non-continuously connected remote OBD and continuously connected remote OBD devices. Allowing use of both would make the program more palatable to affected truck owners, as supported by the fleet survey results suggesting that fleets prefer different testing options based on their size and type of operation. The NCC-ROBD testing device could be a single test unit with a wired connector or wireless dongle, which vehicle owners would simply plug into the vehicle OBD port to initiate OBD data submission process and unplug once the OBD data submission is complete. The CC-ROBD testing device could be integrated onto a vehicle similar to current telematics technologies. Telematics technology has been widely used in the heavy-duty transportation industry to help support fleet logistics needs, vehicle maintenance management programs, and federal electronic logging requirements (FMCSA, 2018). In this case, a similar approach could be taken to the HEM Data Mini Logger where the testing device could be programmed to automatically collect the required OBD data parameters and submit the data to CARB periodically.

Chapter 4 Monitoring Vehicles Entering California Using Automated License Plate Recognition Cameras

Introduction

Trucks registered in other states would have to comply with the HD I/M regulation if they drive on California's roadways. This represents a challenge because a hold on a DMV registration cannot necessarily be executed for vehicles registered in another state (i.e., out-of-state vehicles). Furthermore, identifying out-of-state trucks that enter California can be difficult. To help address this potential issue, staff is considering the installation of ALPR camera systems at border locations to help monitor incoming vehicle traffic. The use of ALPR camera systems potentially represents a way to enhance the identification of out-of-state heavy-duty trucks operating in California and provide an additional enforcement tool to assess vehicle compliance through the cross-reference of the collected vehicle information with a vehicle's program compliance status. If a vehicle is determined to be operating in California without demonstrating compliance with the program requirements, enforcement action can potentially be taken on the vehicle. This, in effect, could help ensure more vehicles operating in California come into compliance with the future HD I/M program.

CARB staff initiated an extramural contract to set up and pilot ALPR camera systems across Southern California. The contract, hereafter referred to as the ALPR pilot contract, has two main goals, to demonstrate the feasibility of using ALPR cameras to collect vehicle information needed to cross-reference compliance status, and provide an opportunity to learn how to refine implementation of the use of ALPR cameras for the future HD I/M program. As such, this chapter highlights some of the lessons learned from these field testing efforts regarding the use of ALPR cameras as an enforcement implementation tool in the future HD I/M program and documents the work performed under this contract related to the installation and operation of ALPR camera systems. Additionally, efforts to improve the use of ALPR cameras in coordination with REMD systems is further detailed in chapter 5 related to the in-house pilot efforts that staff has performed related to PEAQS development

As briefly mentioned above, the ALPR pilot efforts seek to investigate, design, and implement a pilot system that can be used to monitor the activity of out-of-state heavy-duty trucks entering the state through the major interstate gateways and border crossings. This was accomplished primarily by collecting license plate data using ALPR systems at multiple locations along major truck corridors in California with existing infrastructure, such as traffic cabinets, that can facilitate the installation of such technologies. These efforts gave CARB staff experience relevant to future ALPR deployments by completing the following tasks:

1. Research and identify different ALPR camera systems and work to identify the most viable product
2. Install ALPR camera systems at several sites while documenting the deployment process and logistics.
3. Monitor and analyze data collected from ALPR systems and assess their accuracy and efficacy. Metrics for system accuracy under development included correct identification of plate characters and plate State or region.
4. Understand challenges and identify methods to improve ALPR system performance, e.g., through better camera positioning, software tweaks, etc.

Project Status

ALPR systems have been installed at two locations in Southern California. Note that these locations are using ALPR systems from different manufacturers to compare capture rates, including plate character accuracy and region identification accuracy. The total number of license plates and the capture rates at these two locations are shown in Table 4-1 below. Here, capture rate is defined as a successful capture of a license plate by the ALPR system divided by the total number of vehicles passing by. These rates were determined by manual assessment of ALPR camera footage. The two camera manufacturers tested performed similarly in terms of license plate capture rate, capturing between 74 and 77 percent of the total vehicles that travelled by.

Table 4-1. Initial results from two ALPR sites.

SITE	# PLATE RECORDS	CAPTURE RATE	DATA COLLECTION PERIOD
SITE #1	12,233	77%	5/19 – 6/24/2021
SITE #2	38,133	74%	5/26 – 6/15/2021

Lessons Learned

As these ALPR cameras were installed and operated, CARB staff learned valuable lessons from the project that can help improve the technology's implementation effectiveness as part of a future HD I/M program. Overall, the systems tested were determined to successfully capture the majority of vehicles passing through, demonstrating that these systems have the potential to be used as an additional enforcement tool to help monitor a vehicle's compliance status. Additional feedback provided from this field testing is expected to lead to improvements in the future installations of ALPR systems if rolled out as part of the future HD I/M program. Some of these additional lessons learned are highlighted below:

- Certain types of plates are more difficult to recognize than others due to differences in their reflectivity (reflectivity of plates changes from one state to another).
- Roadside power can be inconsistent in some locations.
- Certain times of day present challenges (e.g., lighting). See accuracy percentages for a range of different light conditions in Table 4-2 below. Capture rates ranged from about 70 to 84 percent depending on the time of day.
- Camera positioning and software calibration are key. For example, the ALPR camera's crosshairs should be centered on the license plates.
- Some vehicles are missing their front license plates and will therefore be missed by ALPR systems. Note that only front license plates are monitored to obtain the truck chassis license plate because rear plates for HDVs are often trailer plates unrelated to the truck chassis license plate.
- CARB staff received many details related to the installation of these systems which will help identify ideal locations for future systems and improved staff's understanding of the specific steps and equipment involved in the installation process.

Table 4-2. Time-of-day accuracy of license plate readers.

LIGHT CONDITIONS	ACCURACY
DUSK	84.42%
NIGHT	77.27%
DAWN	70.00%

As ALPR setups are refined and improved beyond this HD I/M pilot, CARB's use of these systems is expected to become more accurate, thereby increasing their effective capture rates. As discussed more in Chapter 5, similar improvements in effectiveness were seen with ALPR cameras installed in collaboration with PEAQS systems as staff improved the system's setup. ALPR systems assessed as part of this pilot effort only monitored the rightmost lane. In the future, staff may try optimizing the camera position to capture vehicles in the right two lanes and, thus, capture a larger population of heavy-duty trucks operating on multi-lane highways. Such efforts could further enhance the effectiveness of ALPR systems to monitor larger populations of vehicles than if only monitoring one lane at a time. Future efforts are also planned to study the effectiveness of using ALPR systems to capture trucks with dual license plates, such as Mexican trucks near the California-Mexico border, in an effort to enhance ways to enforce a future HD I/M program at near border locations. Beyond this pilot effort itself, staff will continue to test out different ALPR camera technologies to assess if one performs significantly better than others. Staff has plans for a third camera manufacturer to be installed at another location in Southern California and will continue investigations into the technology prior to the rollout of the HD I/M program. Overall though, these field efforts demonstrated that ALPR camera technologies can effectively collect vehicle information needed to cross-reference compliance status with the HD I/M program. Future efforts will continue to further optimize the capture rates beyond the rates seen during these pilot field efforts.

Chapter 5 Remote Emissions Monitoring Devices to Support HD I/M

Introduction

As discussed in previous chapters, California's future HD I/M program is expected to require submission of OBD data to verify a vehicle's emissions control equipment is working as required. Older vehicles that do not possess OBD systems would be subject to opacity testing for compliance determination. To complement these emissions testing requirements, CARB staff is considering deploying Remote Emissions Monitoring Devices (REMDs) as enforcement screening tools to monitor emissions from HDVs operating in California. This screening could identify vehicles that have high emissions suggesting the vehicle may be operating with malfunctioning emissions control equipment. Such vehicles could then be required to submit a follow up compliance test such as an OBD scan or opacity test to ensure any issues related to the emissions control equipment have been resolved.

Methodology

REMD systems measure concentrations of various pollutants emitted from vehicles to calculate fuel-based emission factors. REMD systems measure pollutant concentrations with a variety of techniques including plume capture and optical remote sensing. Plume capture systems collect a sample of air containing HDV exhaust emissions as the vehicle passes by the device. The collected air sample is then analyzed by air monitoring equipment to quantify the mass concentrations of emissions. On the other hand, optical remote sensing techniques like UV-infrared (IR) transmittance systems emit beams of ultraviolet light and/or infrared light across or down to the surface of the road. The amount of light absorbed by specific pollutants is proportional to the mass concentration of that pollutant in a vehicle's exhaust. These mass concentrations are then used to estimate vehicle emission factors relative to CO_2 mass concentrations by stoichiometrically converting CO_2 mass concentrations to the mass of diesel fuel combusted. Emission factors are then calculated by dividing mass concentrations of pollutants by the amount of diesel fuel combusted, yielding the final emission factor (EF) form:

$$EF\ [=]\ \frac{g\ pollutant}{kg\ diesel\ burned}$$

Pollutant concentrations that exceed ambient background over relatively short timescales are assumed to be contributions of exhaust emissions from passing vehicles.

Emission factors based on the amount of diesel combusted, such as those produced by REMD, are not directly comparable to in-use standards, which are typically on a per brake-horsepower basis. However, these per kilogram of diesel combusted emission factors are useful screening metrics for current and future enforcement strategies. Vehicles identified as high-emitters could be flagged for follow-up testing via a specified vehicle compliance test, for example, an OBD test. These topics are discussed in the Lessons Learned section of this chapter.

PEAQS

Background

CARB has conducted extensive research and development to create a plume capture-based REMD called the Portable Emissions AcQuistion System or PEAQS. PEAQS units are able to quantify vehicle emissions and can be used to assist in the identification of non-compliant vehicles throughout California. While the initial purpose was to deploy systems to enforce existing in-use regulations, such as the HDVIP, the concept grew to encompass multiple systems, with the understanding that they could eventually become the foundation of a network of REMD to support the future HD I/M system. In 2018, CARB staff began deploying two types of PEAQS systems - “Unattended PEAQS” and “Mobile PEAQS”. Unattended PEAQS can be deployed for long periods of time at fixed locations, while Mobile PEAQS is attached to a mobile trailer allowing it to be deployed in locations without fixed infrastructure. In 2019, CARB staff began testing an upgraded version of these PEAQS units capable of operating in all of California’s varied environments. Upon successful piloting, the network of REMD could potentially grow to be comprised of numerous PEAQS deployed throughout the state to identify high-emitting vehicles for follow-up by CARB staff. This network of REMD may be supplemented with other REMDs developed by outside vendors. As part of this HD I/M pilot effort, several REMDs were evaluated for their potential for incorporation into an enforcement screening program, as discussed in this chapter below.

Current Activity and Pilot Efforts

Mobile PEAQS

CARB deployed Mobile PEAQS at multiple locations throughout the state in 2020 and 2021. During most Mobile PEAQS deployments, high emitting vehicles identified by PEAQS were flagged for inspection immediately after the screening. Enforcement staff then proceeded to conduct a field inspection on the vehicle, and citations were issued if violations of existing CARB programs (HDVIP, ECL, and/or transport refrigeration unit, or TRU) were found.

In 2020, the Mobile PEAQS system was deployed at eight locations, as summarized in Table 5-1 below. Subsequently, PEAQS has been deployed at two locations in 2021 (Table 5-2). The locations of these sites are mapped in Figure 5-1.

Table 5-1. Mobile PEAQS deployment dates and locations in 2020.

DATE	LOCATION TYPE	LOCATION CITY	VEHICLES SCREENED	CITATIONS ISSUED
FEBRUARY 26	CHP Scale	Camino	32	2
MARCH 3 - 4	Port of Entry/CHP	Calexico	801	8
AUGUST 18 - 19	Roadside	Sun Valley	74	N/A
SEPTEMBER 22	Roadside	Calexico	115	3
SEPTEMBER 23	Roadside	Westmorland	229	3
OCTOBER 13 -14	Roadside	Irwindale	404	4
NOVEMBER 2 - 14	CDFA	Mt. Pass	11310	N/A
NOVEMBER 17	Roadside	Fresno	207	4

At two locations ofPEAQS deployments in 2020, no inspections were conducted and no citations issued. First, the CDFA Mt. Pass deployment from November 2 – 14 was part of the pilot efforts discussed in detail later in this chapter. No citations were issued at Mt. Pass to drivers participating in the voluntary pilot. Second, CARB staff, in collaboration with Los Angeles Public Works (LAPW), also deployed PEAQS in Sun Valley on August 18-19, 2020 in response to community complaints regarding the Devil's Gate reservoir restoration project. Per LAPW request, no citations were issued in order to minimize traffic delays in the region.

In 2021, as of the writing of this report, Mobile PEAQS had been deployed 11 times, and inspections were conducted at all deployments (see Table 5-2 below). CARB will continue Mobile PEAQs deployments throughout the remainder of 2021.

Table 5-2. Mobile PEAQS deployment dates and locations in 2021.

Date	Location Type	Location City	Vehicles screened	Citations Issued
March 16 - 17	CHP Scale	Otay Mesa	1251	11
March 23 - 24	Roadside	Port of LA/LB	1159	12
April 13 – 14	CHP Scale	Winterhaven	611	12
April 20	Roadside	Lake Elsinore	451	6
May 11 - 12	Roadside	Los Angeles	693	16
May 18 - 19	Roadside	Santa Maria	379	6
May 25	CHP Scale	Calexico	523	6
May 26	Roadside	Westmorland	256	6
June 15 - 16	Roadside	Los Angeles	520	12
July 13 – 14	Roadside	Port of LA/LB	1780	14
July 20 - 21	CHP Scale	Otay Mesa	1275	16

Over 2020 and 2021, CARB conducted 19 deployments of Mobile PEAQs. Figure 5-1 displays all 13 unique locations where Mobile PEAQS were deployed on a map of California (several locations were visited more than once). In addition, CARB screened 22,740 vehicles and issued 141 citations for non-compliance with our current regulations. These mobile deployments demonstrated that PEAQS is an effective tool for screening vehicles and for identifying non-compliance.

Figure 5-1. Locations of the 13 PEAQS deployment sites in 2020-21. Also shown are California highways and county borders.

Unattended PEAQs

For this pilot effort, CARB built and deployed two prototype PEAQS for long-term unattended deployment. The first unit, shown in Figure 5-2, was deployed in San Bernardino County in 2019. Except for two short periods where the unit underwent maintenance and repair, this site has been in continuous operation since 2019. The second unit was deployed in Riverside County in 2020. This system operated normally until December of 2020, at which point it was returned from the field for maintenance and upgrades. It will be replaced with an upgraded version, as discussed further in the Lessons Learned section of this chapter.

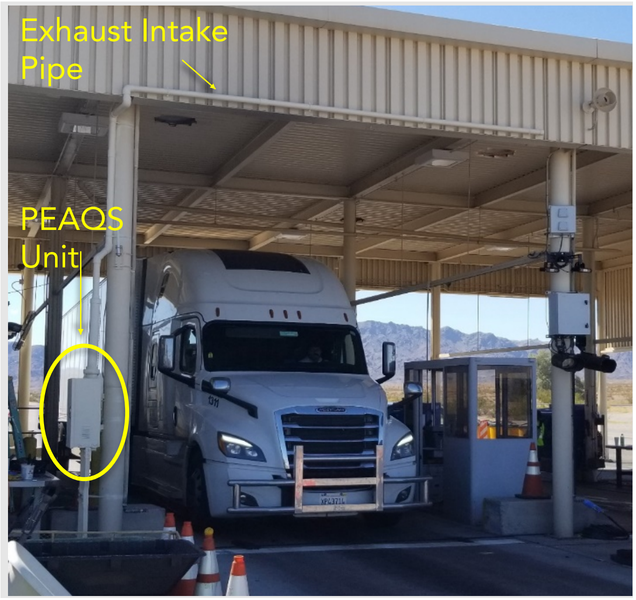


Figure 5-2. Unattended PEAQs system in operation.

The two unattended PEAQS systems have collected significant amounts of data, including traffic details, as summarized in Table 5-3. Vehicles Screened at PEAQS Semi-permanent Pilot Sites.Table 5-3. These prototype units have screened an average of 41,000 vehicles operating within California every month. Aggregate emissions data are not included in this report because data analysis mechanisms to separate TRU emissions from vehicle emissions are continuing to be refined (see Lessons Learned section below). Individual vehicle data (including emissions) are also not provided as these data are being used to support enforcement actions related to current regulations.

Table 5-3. Vehicles Screened at PEAQS Semi-permanent Pilot Sites.

Total Vehicles Screened	238,000
% Registered in CA	47%
% Out-of-State	53%
Average Monthly Vehicles, San Bernardino	8,000

Average Monthly Vehicles, Riverside	33,000

Concurrent REMD Testing

Due to the inherent differences in REMD measurement techniques, it was important to pilot vehicle testing techniques concurrently to assess how best to utilize these different vehicle measurement techniques in a complementary manner. In an effort to help understand nuances between the methods, for the first two weeks in November of 2020, CARB staff, in coordination with CDFA staff and participating contractors, piloted potential vehicle compliance tests techniques such as OBD and opacity testing in combination with multiple REMD platforms that have the potential to be used as emissions screening tools. This piloting effort occurred at a CDFA inspection site on the Nevada-California border at Mountain Pass and aimed to begin to answer questions related to the potential interplay between REMD systems and potential vehicle compliance tests such as:

- Can currently available REMD systems identify high emitting vehicles with potential emissions control-related issues?
- Could different REMD systems be used together as part of a future statewide network?
- How do vehicle emissions measurements from REMD systems relate to potential vehicle compliance tests that may be used as part of the future program such as OBD and opacity?

Site description

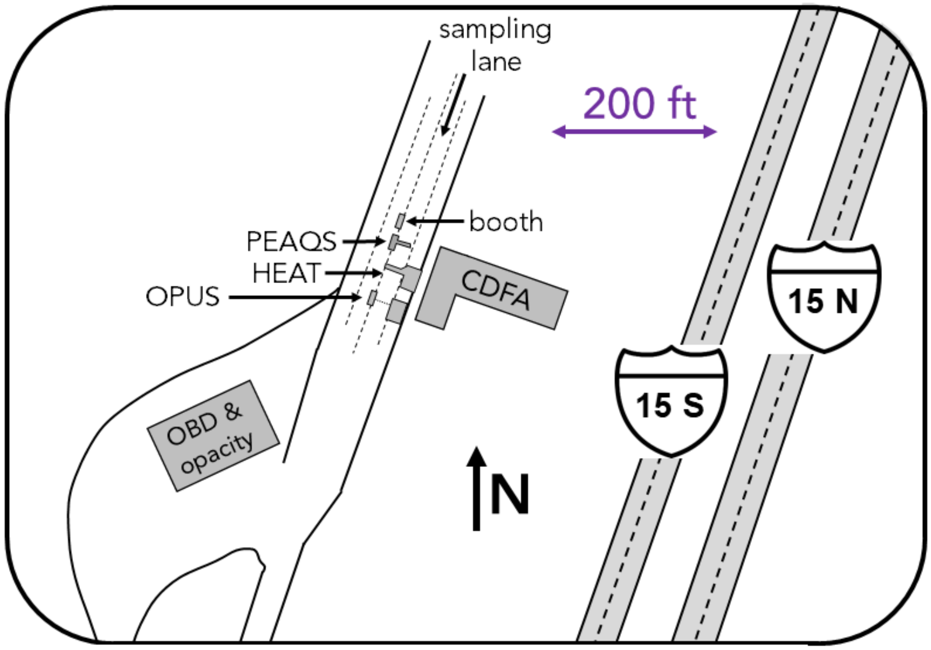


Figure 5-3. Diagram of the field site at Mt. Pass.

As shown in Figure 5-3, this piloting effort deployed three testing systems at the agricultural inspection station at the California-Nevada border along Interstate 15 (I-15). This station is located at 35.5161°N / 115.4319°W and is run by CDFA. This station has an Annual Average Daily Traffic (AADT) of 44,000 vehicles and 7,902 HDVs. The trucks entering California pass through the station immediately after climbing a 1.6 percent road grade averaged over the first 10 miles of I-15 south of the California-Nevada border, thus, it is expected that aftertreatment catalysts sampled during this campaign are above light-off temperatures. This station includes four HDVs lanes parallel to the I-15S highway. Emissions were measured from HDVs traveling along the second ("sampling") lane by three REMD systems – PEAQS, a system operated by Hager Environmental & Atmospheric Technology (HEAT), and then one operated by Opus Inspection, Inc. This sampling lane was the preferred lane for HDV traffic, and typically about half of the HDVs passing through the station did so in this lane.

A subset of the HDVs passing through the sampling lane was flagged for additional opacity testing and scans of their OBD system. These HDVs were selected at a CDFA booth situated immediately before passing through the REMD systems. Vehicle selections were made in an effort to obtain a representative sample of various OEMs and MYs. HDVs were observed by the three REMD systems, and immediately afterward drove over to the adjacent

OBD and opacity testing area. Participation in the opacity testing and OBD scans was voluntary, but a large majority (> 80 percent) of selected vehicles agreed to this testing.

In the sampling lane, emissions were first measured by CARB's PEAQS plume capture system. This system involved a sampling inlet comprised of perforated tubing crossing the lane above the height of the HDVs, as well as a lower inlet just above the ground along the side of the road. Immediately afterward, the HDVs were sampled by HEAT. This system involved a spectroscopic transmitter and receiver mounted about the roadway and a strip of retroreflective tape across the roadway below. Finally, emissions were measured by OPUS, which involved a spectroscopic transmitter and receiver mounted on either side of the road. OPUS used two horizontal spectroscopic beams – one a few inches off the road which targeted HDVs with downward-oriented exhaust pipes, and one approximately twelve feet off the ground which targeted upward-oriented pipes. All three systems reported fuel-based emissions factors - i.e., grams (g) NO_x or g PM per kilogram (kg) fuel.

HDVs flagged at the entry booth for secondary testing were subject to tailpipe exhaust opacity testing, using the SAE J1667 protocol. Results of this test are reported as a percentage. Opacity results above five percent for DPF-equipped vehicles are considered to have failed the test, although no citations were issued during this campaign. Applicable HDVs also had their OBD systems scanned, with scan devices manufactured by Silverscan and HEM Data.

PEAQS

CARB deployed a Mobile PEAQS unit at the Mt. Pass site (Figure 5-4). Fuel-based emission factors for NO, nitrous dioxide (NO_2), BC, and N_2O were quantified. Results for BC and NOx (NO + NO_2) are compared to other measurement systems below. Further details related to the PEAQS design and operation were discussed earlier in this chapter

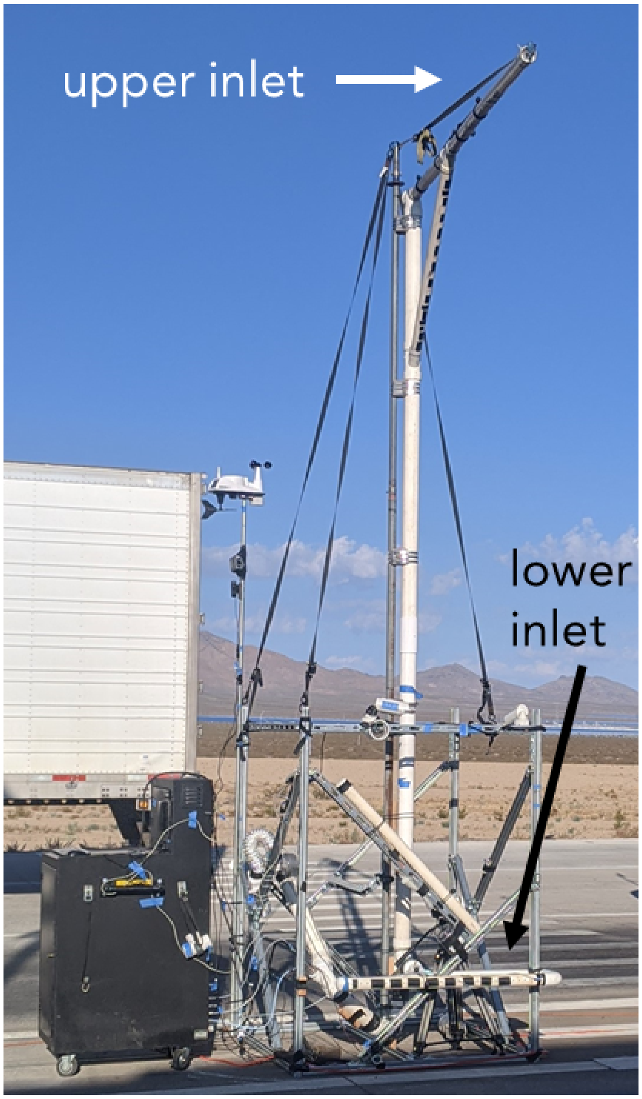


Figure 5-4. PEAQS unit in operation at the Mt. Pass testing site. Both the upper and lower sampling inlets are labelled.

HEAT

CARB contracted with HEAT to measure emissions from HDVs in the sampling lane. Using their EDAR system, HEAT measured fuel-based emissions of PM, NO, NO_2, carbon monoxide, and hydrocarbons (HC). EDAR involves an ultraviolet (UV)-visible light transmitter and receiver, mounted above the roadway and oriented downwards, along with a retroreflective strip installed across the roadway (Figure 5-5). It measures the differential absorption of various wavelengths of light as it travels downward from the transmitter, is reflected upward by the tape, and finally is received at the same location as it was emitted.

Figure 5-5. HEAT's EDAR system in operation at the Mt. Pass testing site. The combined transmitter/receiver is labelled.

OPUS

CARB contracted with Opus Inspection, Inc. to measure fuel-based emissions of PM, NO, NO_2, CO, and HC from HDVs in the sampling lane. The Opus system includes a UV-IR transmitter/receiver on one side of the road, and a reflector on the other (Figure 5-6). The absorption of light crossing the roadway in two beams was measured; the first beam was several inches off the ground and targeted HDVs with exhaust pipes below the vehicle, while the second was approximately 15 feet above the roadway and targeted HDVs with upward-oriented exhaust pipes.

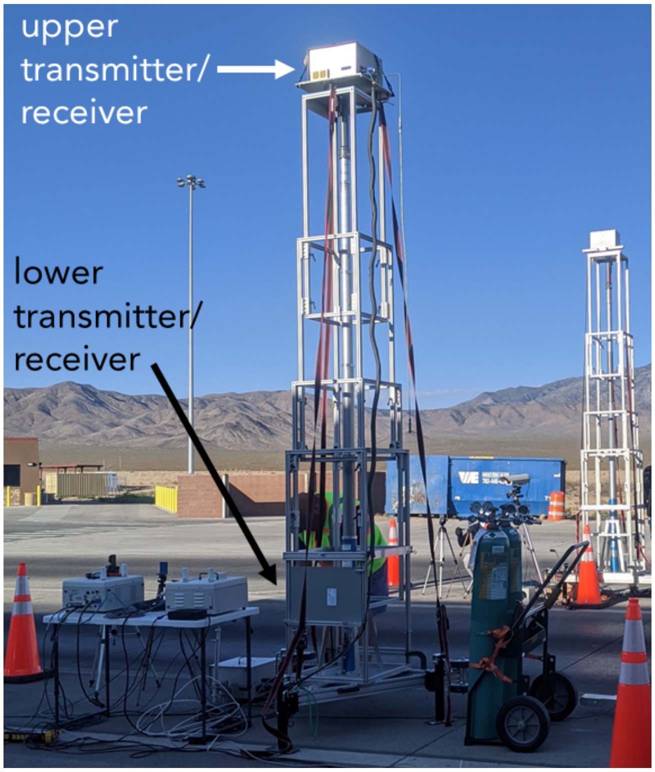


Figure 5-6. The Opus system in operation at the Mt. Pass testing site. Both the upper and lower combined transmitter/receivers are labelled. These use reflectors mounted on the tower on the other side of the road.

OBD scans

In addition to the fuel-based emissions factors observed by the spectroscopic and plume capture systems, a subset of the HDVs passing through these systems were also subject to scans of their OBD systems. Of the 169 HDVs sent to the inspection area, 127 (75 percent) agreed to the additional testing, 103 of which were OBD-equipped vehicles. Two devices were used to communicate with the OBD systems: a stand-alone logger manufactured by HEM Data, and PC software developed by Silverscan. Both devices were configured to record MIL status, active DTCs, diagnostic readiness, permanent DTCs, current drive cycle monitor status, and other engine information. The data collected in this pilot effort was similar to the data collected in the study described in Chapter 3 above.

Opacity Testing

Opacity readings were made on 118 HDVs following the SAE J1667 protocol. SAE J1667 applies to vehicle exhaust smoke measurements made using the Snap-Acceleration test procedure. The Snap-Acceleration Test procedure is completed on a non-moving vehicle and can be conducted along the roadside. It is designed to be used in conjunction with smoke meters using the light extinction principle of smoke measurement. A Red Mountain Smoke Check 1667 meter was used for testing, the same smoke opacity meters used by CARB Enforcement Field Representatives for field inspections.

Results

Vehicle Counts

Measurements were made from approximately 8 AM to 4 PM on 11 days: November 2 to 7 and 9 to 13, 2020. Emissions measurements were obtained from 12,837 HDVs passing through the RSD sampling lane. License plates from 9,499 unique vehicles were recorded, reflecting the multiple passes that many individual HDVs made over the eleven-day campaign. Many vehicles passed multiple times during the study; 61 HDVs passed through on at least six different days, and 506 passed through on at least three different days. Table 5-4 lists the number of observations made by each system.

Each REMD system was able to report emissions from a subset of the total HDVs that passed through the sampling lane. Many factors contribute to the various REMD systems not producing a 100 percent hit rate of valid emissions measurements for vehicles passing through the systems once data has completed quality assurance/quality control (QA/QC) checks, thus the measured hit rates are as expected. Reasons why emissions measurements may have been removed during the QA/QC process, and hence not reported, include interference from other vehicles, unfavorable wind conditions, measurements below the detection limit, and low signal-to-noise ratio, as well as others.

Table 5-4. Number of observations made by each system.

SYSTEM	VALID OBSERVATIONS
OVERALL	12,837
PEAQS	6,277
HEAT	8,987
OPUS	5,685

Measured by at least one REMD system

During this pilot effort, just over half of the vehicle population recorded was from jurisdictions outside of California (Table 5-5). Although the most common age range for both the in-state and out-of-state vehicles was the 2014-2017 MY range, the out-of-state HDVs were generally newer than in-state vehicles, as shown in Table 5-5, with nearly all out-of-state vehicles detected being 2014 MY or newer. Out of all out-of-state license plates detected, 49 percent were matched to the International Registration Plan. Out of observed California plates, 89 percent were matched with CA DMV registrations.

Table 5-5. Distribution of sampled trucks by age and license plate state.

CHASSIS MODEL YEAR	IN-STATE	OUT-OF-STATE
TOTAL	46.4%	53.6%
PRE-2007	0.8%	1.5%
2007-2009	3.1%	2.2%
2010-2013	11.2%	6.4%
2014-2017	21.4%	31.0%
2018-2021	9.9%	12.6%

Repeat measurements of individual HDVs

Over the course of the two-week, eleven-day campaign, many HDVs were observed multiple times by the REMD systems. Figure 5-7 shows that, for both NOx and PM emissions, hundreds of HDVs were measured at least three times by an individual system, and nearly fifty were measured at least five times. This relatively high repetition rate for the campaign allowed for an investigation of intra-system variability for individual vehicles passing through a system at different times. For this analysis, it is assumed that no changes to a vehicle's emissions control system occurred between measurements. For example, it is assumed that the durability of the emissions-related components is unchanged from the previous measurements and that no repairs or replacements of emissions-related parts occurred within the sampling window. Such assumptions are reasonable for emissions measurements within a short time period like the two-week sampling period under which this testing occurred.

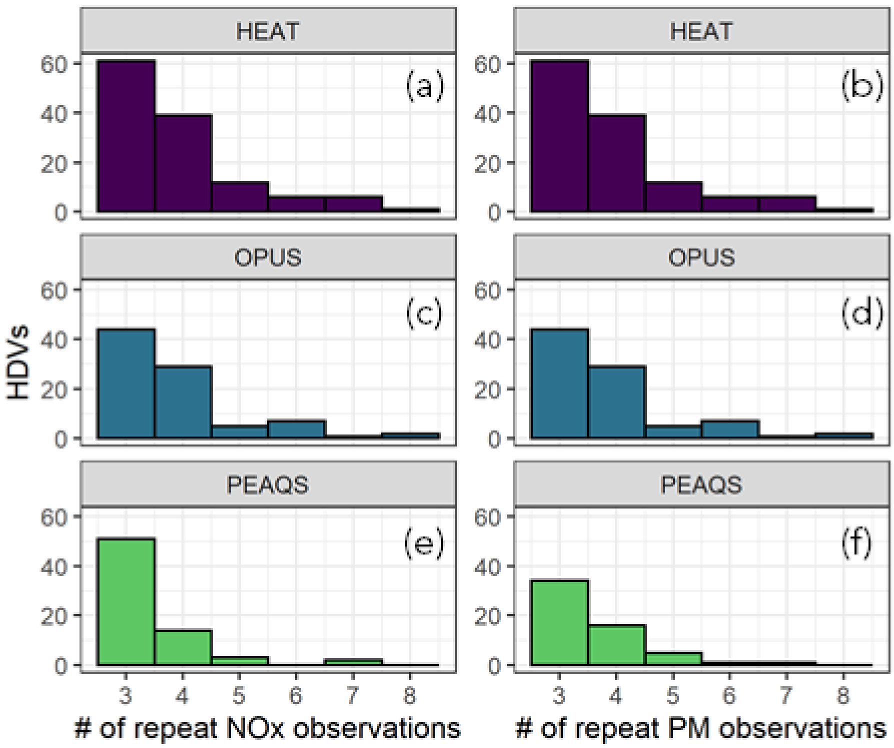


Figure 5-7. Number of repeat measurements of HEAT (a) NOx and (b) PM, Opus (c) NOx and (d) PM, and PEAQS (e) NOx and (f) PM. Note that only HDVs observed at least three times are shown.

Figure 5-8 depicts the average emissions for each HDV with a pollutant measured at least three times by the same REMD system, plotted from lowest emission measurement to highest. The error bars in Figure 5-8 indicate the standard error of the emissions measurements from repeat vehicles passing through the REMDs at different times during the campaign. For NOx emissions, average values for standard error were around 3 g NOx/kg fuel; the maximum standard error for a vehicle was 20 g NOx/kg. For PM emissions, average values for repeat measurement standard error were around 0.1 g PM/kg fuel; the maximum standard error for a vehicle was 3g PM/kg.

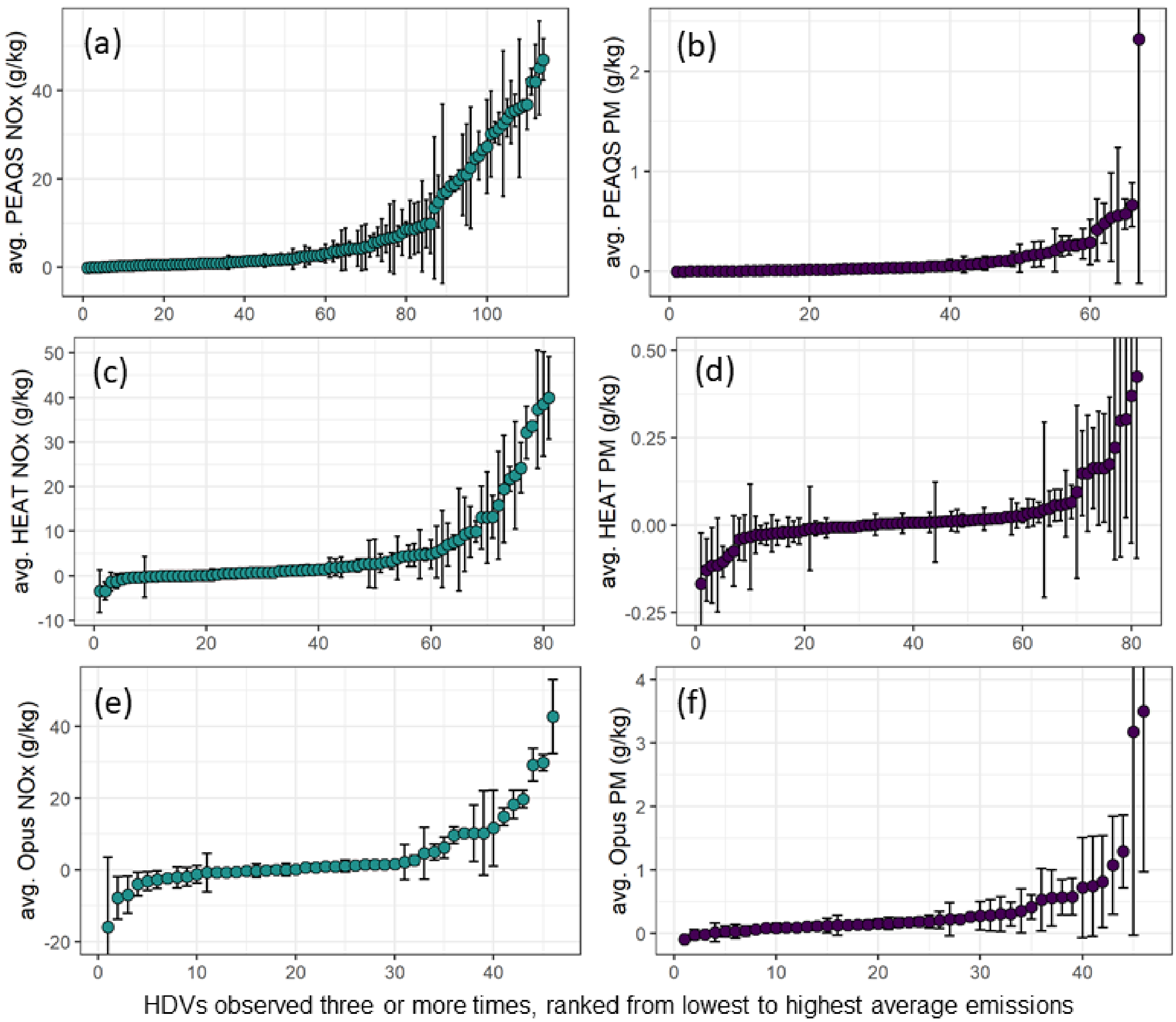


Figure 5-8. Average emissions of NOx (left) and PM (right), ranked from lowest to highest average emission measurement, for HDVs observed at least three times. Error bars depict standard error. (a) and (b) PEAQS; (c) and (d) HEAT, and (e) and (f) Opus.

Examination of the highest-emitting repeat measurement vehicles can give insight into the potential of individual REMD measurements to consistently identify potential high emitting vehicles if used to screen vehicles for future I/M action. A useful screening tool should flag the same high-emitting HDVs from day to day assuming everything else is constant. For all three systems, high emitting NOx vehicles could be reasonably and consistently identified during this campaign. The error bars between repeat measurements on these vehicles are small compared to the relative magnitude of the emission measurement and show that even with potential day-to-day variability, the vehicle's NOx emissions remained high. For example, the 18 highest emitters of NOx (16% of HDVs) as measured by PEAQS all were significantly (based on standard error) higher than 16 g / kg fuel. The highest six (5 percent) all were significantly higher than 31 g / kg (Figure 5-8a). Similarly, for HEAT, the eight highest NOx emitters (10 percent of HDVs measured at least three times) all were significantly higher than 10 g / kg (Figure 5-8c), and for OPUS, the top six (13 percent) were all significantly higher than 12 g / kg (Figure 5-8e). Based on these repeat measurements, all three REMD systems were able to reliably identify the highest NOx emitters (i.e., the top ~10%, or above ~10 g / kg). This indicates that the same HDVs would be flagged as high emitters from one day to the next. Overall, these results suggest that REMDs have the potential to be able to screen for vehicles with high NOx emissions.

Repeat measurements of PM emissions from individual vehicles were not nearly as consistent as for NOx emissions in this campaign. This is evident by the larger error bars (standard errors) relative to the magnitude of emissions measurements for PM, especially for vehicles that measured at the high end of the spectrum. The resulting day-to-day variation associated with the repeat PM emissions measurements during this campaign may be related to changing driving patterns of the vehicles in question at the time of measurement. Large spikes in PM emissions are typically correlated with acceleration events in a vehicle's driving pattern, thus any inconsistency in a vehicle's acceleration profile can impact the emissions measured from the vehicle. However, this repeatability may be less critical for PM-related high emitter screening relative to NOx screening. Considering HD vehicles operating in CA are predominantly operating with DPFs, any excess PM measurements, excluding regeneration events, are typically a sign that a vehicle's emissions control system has an issue. A properly functioning DPF reduces PM emissions by over 99 percent, thus effectively operating near background levels when functioning properly. So even if vehicle PM emissions may be inconsistent, identifying high PM emissions a couple times over the span of a short period to eliminate the anomaly that the vehicle may be passing through during a regeneration, may be enough to signal a potential maintenance issue. Testing will continue beyond this pilot effort to further identify the best methods to use REMDs as screening tools within the future HD I/M structure, however, upon investigations undertaken before and during this pilot effort, these systems have a strong potential to identify high emitting vehicles.

OBD scans

Summary

A total of 103 HDVs passing through the sampling lane were selected for OBD scans. The median engine MY for this sample set was 2017, and Figure 5-9 lists the engine OEMs observed, along with the number of HDVs for each. OBD data scans were obtained for 102 of these. One MY2013+ HDV from which OBD data was not obtained had a damaged OBD port. OBD data was therefore obtained from just over 99% (102 out of 103) of OBD-equipped HDVs selected for OBD testing.

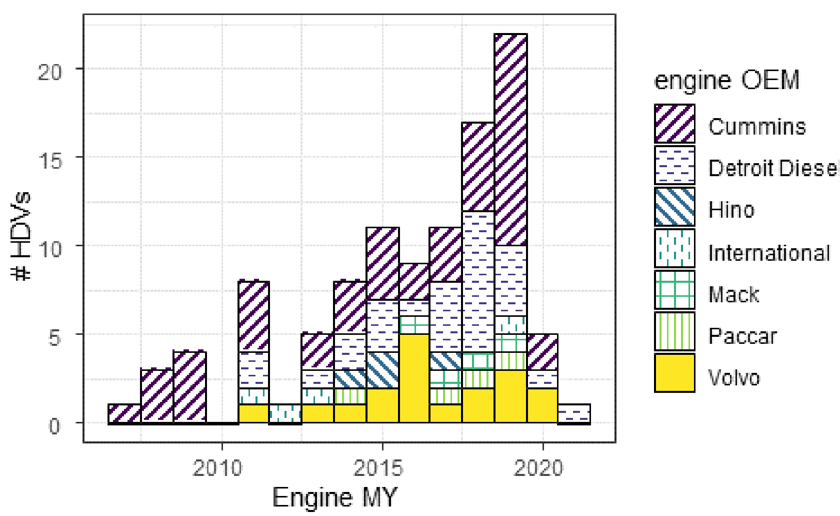


Figure 5-9. Engine MY distributions for HDVs subject to OBD scans. Color indicates engine OEM.

Malfunction Indicator Lamp status and Diagnostic Trouble Codes

Out of the 102 OBD-equipped HDVs that were scanned, 17 had their MIL illuminated resulting in a 17 percent MIL-on rate for the vehicles tested. Given the relatively small sample size of OBD tests in this two-week effort, this value is reasonably consistent with previous OBD test campaigns which have suggested a MIL-on rate around the 12 percent range. Nine of the seventeen engines had DTCs related to SCR operation (including the NOx sensors contained within the aftertreatment), making this the most common type of DTC observed. Five of these engines had DTCs related to engine operation, four had DTCs related to DPF performance, three had DTCs related to EGR, and one had a communications issue (note that some HDVs had DTCs in multiple categories).

Table 5-6 lists the DTCs associated with the MIL-on engines, and classifies them as either “active”, “pending”, or “permanent” as specified by the OBD scans. Between one and four DTCs were reported for each engine. As expected, every vehicle with an illuminated MIL had an active fault code associated with the vehicle’s emissions control system. Of the total 29 active codes, 23 had a permanent fault code associated with the same emissions control issue. Permanent codes stay in the OBD system’s memory even if fault codes are cleared and can only be removed once the vehicle has determined the fault detected is no longer present. These permanent codes can be a critical component in combatting fraudulent activity such as unhooking the battery or using a scan tool to clear fault codes prior to the submission of an OBD compliance test. The fact that a permanent code is associated with a high percentage (23 of 29, or 79 percent) of active codes collected in this effort suggests that incorporating permanent codes into compliance determination could help effectively combat some of the fraudulent activity that may occur prior to the submission of OBD tests.

Table 5-6. List of MIL-on engines and associated DTCs.

Engine MY	OEM #	DTC	active	pending	permanent
2017	1	Engine Crankcase Breather Oil Separator Speed	■		■
2018	1	Aftertreatment 1 Intake Gas Sensor 1 Heater Control	■		■
		Aftertreatment 1 SCR Intake NOx 1	■		■
2018	1	Engine Crankcase Breather Oil Separator Speed	■	■	■
2015	2	Aftertreatment 1 SCR Outlet Temperature	■	■	■
2014	2	Engine Coolant Level	■	■	■
2014	3	Aftertreatment 1 SCR Conversion Efficiency	■	■	■
		Engine Fuel Injection Pressure Error	■	■	■
		Engine Fuel Pump Pressurizing Assembly #1	■	■	■
2018	4	EGR "A" Flow Insufficient Detected	■		
2013	4	EGR Temperature Sensor "A" Circuit	■	■	■
		NOx Sensor Circuit	■	■	■
		NOx Sensor Circuit High	■	■	■
		NOx Sensor Heater Control Circuit	■	■	■
2015	4	NOx Sensor Circuit	■	■	■
		NOx Sensor Circuit High	■	■	■
2015	4	Cold Start SCR NOx Catalyst Inlet Temperature Too Low	■		■
		Exhaust Aftertreatment Fuel Injector "A" Performance	■		
2016	4	Particulate Filter Efficiency Below Threshold	■	■	■

Engine MY	OEM #	DTC	active	pending	permanent
		SCR NOx Catalyst Efficiency Below Threshold	■	■	■
		Ambient Air Temperature Sensor Circuit "A"		■	
		Reductant Tank Temperature Sensor "A"		■	
2016	4	PM Sensor Regeneration Incomplete	■	■	■
		PM Sensor Circuit Range/Performance	■	■	
2016	4	PM Sensor Regeneration Incomplete	■	■	■
		Turbocharger/Supercharger "A" Overboost Condition	■		
2015	4	NOx Sensor Performance - Sensing Element	■		
		NOx Sensor Heater Control Circuit Range/Performance	■		
		Catalyst System Efficiency Below Threshold		■	
2020	4	Lost Communication with Anti-Lock Brake System (ABS)	■		
2018	5	SCR NOx Catalyst Efficiency Below Threshold	■	■	■
2019	4	EGR "A" Flow Insufficient Detected	■		■

MIL-on duration

In addition to indicating MIL status, when the MIL is on, OBD systems report both (1) the distance the vehicle has traveled since the MIL was first activated and (2) the time the engine has been on since the MIL was first illuminated.

CARB has two sources of OBD data that include this information: the field campaign at Mt. Pass in November 2020 (seventeen HDVs, engine MYs 2013-2020), and the Truck and Bus Surveillance Program (eight HDVs, engine MYs 2015-2017). This latter program, which began in 2016, includes recruitment of in-use HDVs, followed by measurement of their emissions using both a chassis dynamometer and a PEMS. OBD scans are also collected. To obtain a larger sample size, these data sets were combined for this analysis.

Of the twenty-five HDVs with their MIL on, roughly half indicated that the MIL had been activated relatively recently. Specifically, for about half these HDVs, the MIL had been active for less than 100 engine-on hours (Figure 5-10), or less than 5,000 km (3,100 miles) traveled (Figure 5-11). The remaining half of these trucks had their MILs on for a wide range of durations. These MIL-on durations were spread evenly throughout the full range of possible reported values (up to 65,535 km, or 1,092 hours).

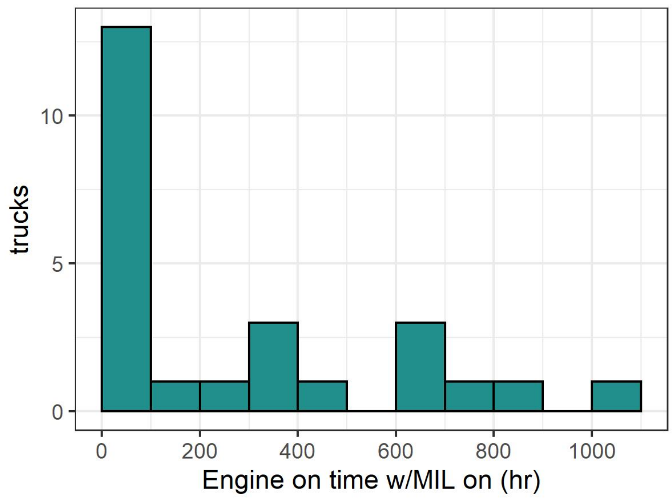


Figure 5-10. Distribution of engine-on time (hours) with MIL on, for HDVs with MIL on at the Mt. Pass site and in CARB's Truck & Bus Surveillance Program.

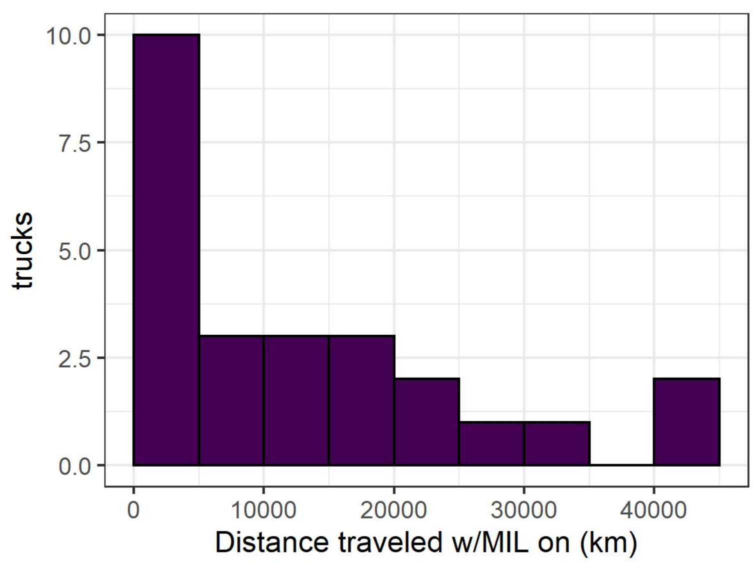


Figure 5-11. Distribution of distance travelled with MIL on, for HDVs with MIL on at the Mt. Pass site and in CARB Truck & Bus Surveillance Program.

Although this is a limited data set, the fact that about half of vehicles were operating with MIL-on for extensive amounts of time (i.e, more than 100 engine-on hours or 5,000 km (3,100 miles) traveled) highlights the need for an HD I/M program as a whole and highlights the need for frequent testing. The data suggests the potential that MILs are not being addressed quickly, and that a regulatory program such as a future HD I/M program can help create an incentive to prompt quicker repair action when a MIL is illuminated.

Opacity Measurement Results

CARB staff completed SAE J1667 opacity testing on 118 trucks. Eight of these (seven percent) measurements were above the five percent opacity limit for failure for DPF-equipped vehicles. For 96 of these (81 percent), the opacity measurement was 0 percent. All eight of the trucks that failed opacity testing had engines with engine MY older than 2013 (Figure 5-12).

No OBD equipped trucks failed the opacity test, yet 17 percent of them had illuminated MILs. Three percent of MIL-on vehicles had a DPF-related fault code, and yet still passed the smoke opacity test. This highlights an important potential feature related to these two vehicle compliance test types. OBD inspections are likely a stronger inspection method relative to the opacity test, and can more readily diagnose emissions control issues. This is highlighted by the fact that an OBD emissions test can diagnose potential malmaintenance issues prior to the emissions component completely failing. This is in contrast to the opacity test, where a failing result typically signifies that a DPF has failed and must be replaced. By the time the opacity threshold is exceeded, there is very little that can be done to salvage the DPF on the vehicle being tested. Although the sample size was small, it is still notable that no OBD equipped vehicles failed the opacity test. The observations that an OBD test is considered a stronger compliance inspection method than the opacity test and that no OBD-equipped vehicles failed the opacity test during this study potentially suggests that requiring an opacity test in addition to an OBD test simultaneously as part of a future HD I/M compliance test requirement for OBD vehicles may not be needed.

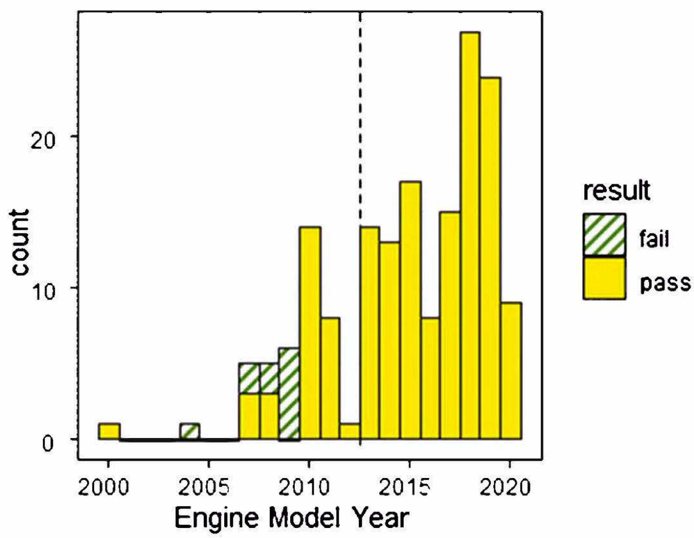


Figure 5-12. Engine MY distribution for trucks subject to opacity testing. Results of this testing are indicated by color (hatched green = fail, solid yellow = pass).

Comparison Among PEAQS/RSD and OBD Scans/Opacity Testing

The limited data set made it difficult to form strong conclusions about the relationship between REMD and potential vehicle compliance tests that may be used as part of the future HD I/M program. However, the data did show that the combination of REMD and follow-up OBD compliance tests could effectively capture a portion of non-compliant vehicles and ensure they are brought back into compliance. As noted, only 17 vehicles tested during this pilot effort had illuminated MILs. Of these tested vehicles, there was a mix between those that would have met the criteria to be considered a high emitter from one of the REMD and those that would not have been flagged by an REMD for further follow-up. Figure 5-13 offers an illustrative example of the relationship between REMD measurements and OBD MIL status as collected during this study. This figure depicted REMD measurements collected on the HEAT system with the horizontal lines representing the 95th and 97th percentiles of REMD emissions measurements, with markers above the lines representing vehicle emissions measurements in the top five and top three percent of those that were measured. Of the 17 MIL-on vehicles identified during this campaign, the majority of them would not have been identified as potential high emitting vehicles under a simple “top five percent” high emitter threshold within the REMDs themselves.

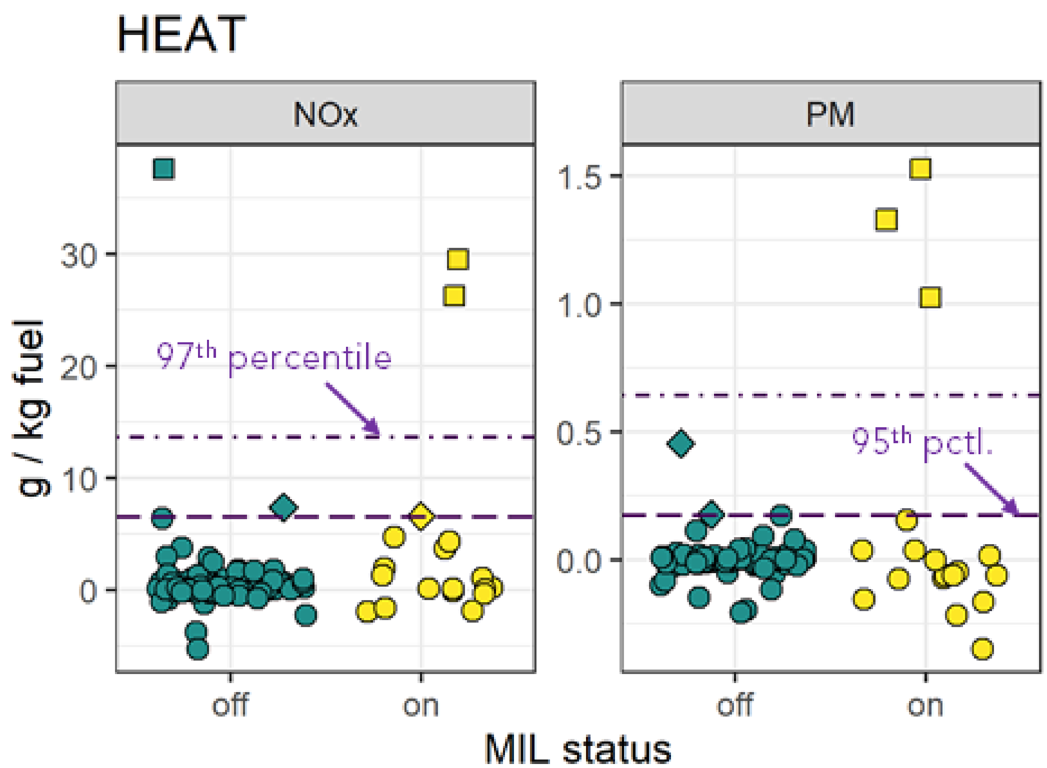


Figure 5-13. NOx (left) and PM (right) emissions measured by HEAT vs. MIL status. Horizontal lines indicate the 95th and 97th percentiles of all HEAT measurements. Points in the top three percent are squares, points in the top three to five percent are diamonds, and points in the lower 95 percent are circles.

Such a result is not unexpected, as a simple "top five percent" threshold is not robust enough to capture all the nuances of vehicle emissions. Collecting additional emissions data to improve REMD's abilities to capture these nuances would result in REMDs capable of serving as strong screening tools, a deterrence to non-compliance, a method to screen between periodic testing, and a powerful tool to assess fraudulent activity. For example, vehicles submitting compliant periodic tests, but consistently operating at high emissions may suggest the vehicle should be looked at more carefully either for fraudulent activity or for malmaintenance between periodic testing. Thus, a program structure incorporating a periodic testing component in conjunction with REMD would result in greater emissions reductions overall and identify emissions-related repair issues earlier, rather than solely relying on REMD systems or periodic testing alone.

Lessons Learned

There were many lessons learned throughout the deployments of these REMDs. A discussion of these lessons learned is below. As a follow-up to this pilot, CARB staff are working to implement upgrades to improve the efficacy of REMDs like PEAQS.

Concurrence Testing

Three different REMDs were used to measure fuel-based PM and NOx emission factors from nearly 13,000 trucks crossing the CA-NV border over a two-week period in November 2020. The large number of vehicles measured on at least three separate days allowed intra-vehicle variability to be investigated. For repeated NOx measurements, vehicles with the highest average emissions (above ~10 g / kg fuel, or the top ~10%) were consistent, meaning that emissions were consistently high during individual passes through the REMDs. Overall, these results suggest that REMDs have the potential to readily identify high-emitting NOx HDVs for further I/M action.

In contrast, when PM emissions were measured from the same HDVs on multiple days, the individual measurements were much less consistent. Although not always repeatable and potentially due to variance in vehicle acceleration patterns, such repeatability may not be as critical for PM emissions measurements considering how effective DPFs are at minimizing PM emissions when functioning properly. PM measurements significantly above background levels potentially signal DPF related issues regardless of whether such measurements are always repeatable or not. Further testing will continue beyond these pilot efforts to further identify the best opportunities to use REMDs as screening tools within a future HD I/M structure, however, upon investigations undertaken before and during this pilot effort, these systems have a strong potential to identify high emitters.

Slightly over 100 vehicles were pulled over during the campaign for additional testing, including a scan of their OBD systems and a "snap-idle" opacity measurement. OBD data was obtained from 102 engine MY 2013 and later trucks. The MIL was illuminated in 17 percent of this subset, and approximately one-third of these had their MIL illuminated relatively recently (i.e., less than 100 hours of engine run time, or 5,000 km traveled). The majority had their MIL active for longer periods and distances. This suggests that an I/M program would have an impact on the speed at which emissions-related repairs are completed in the real world, leading to substantial emissions benefits by addressing these issues sooner. In terms of the individual components associated with MIL-on engines, the SCR catalyst was the most prevalent. A majority (95) of the vehicles tested had zero opacity, and eight (7 percent) failed the opacity test. All the trucks that failed the opacity test had engines older than MY 2013, and therefore were not OBD-equipped. The fact that OBD equipped trucks failed 17 percent of the time, but never failed an opacity test confirmed the need to move to OBD tests where feasible to diagnose emissions-related issues. Furthermore, this data suggests that adding an opacity test as an additional compliance test beyond an OBD scan for OBD equipped vehicles may not be a cost-effective approach to setting up an HD I/M program.

The relationship between REMD emissions and MIL status was not always consistent during this campaign using simple high emitter determinations such as "top five percent" of vehicle emissions measured in the REMDs. However, as mentioned previously, this result is not unexpected using a simplistic high emitter determination approach. The study highlighted the need to roll out REMD carefully and constantly monitor the outcomes so as to be sure a large number of vehicles are not being directed for further testing without identifiable or repairable emissions-related issues.

ALPR Implementation

Prior to unattended pilot deployments, PEAQS systems were periodically collecting static images from the ALPR camera and then post-processing these images with ALPR software. However, staff found that directly accessing the real-time stream improved the ALPR system's ability to identify license plate information. Implementing this new streaming ALPR improved the system's capture rate from ~80 percent to ~90 percent.

Matching Vehicle Emissions to their License Plates

The commercial ALPR software used in the PEAQS and other REMD systems generally performs very well, providing a 90 percent or higher capture rate (see above). However, there are occasional instances when a license plate is undetected by the software due to various reasons, such as blocked/obscured license plates and adverse lighting conditions. If this happens in combination with tailgating traffic, the chances that a vehicle's emission readings are misattributed to the following vehicle increases. To address this issue, REMDs may benefit from utilizing additional sensors like Laser Ranging Sensors as an additional vehicle detection mechanism.

Transport Refrigeration Unit Exhaust Mixing

HDV exhaust pipes come in two general configurations, either upward-pointing stacks with the exhaust emitted above and behind the cab of the HDV (updraft), or downward-facing exhaust pipes that emit below and behind the cab of the HDV (downdraft). In updrafts, TRU and HDV exhausts are located within a few feet of each other and their plumes can mix prior to being measured by an REMD. In the case of downdraft exhaust, TRU exhaust plume (if captured) and the HDV exhaust plume are either mixed in the transfer line, or they hit the sensor array within several seconds of each other. When this occurs, associating one with the HDV exhaust and the other with TRU is a challenging task. Addressing this challenge will likely require the integration of additional detection methods and/or computer vision techniques to confirm the presence of a TRU and subsequently determine the statistical likelihood of the emissions source (HDV exhaust or TRU).

Meteorological Impacts

Meteorological factors, particularly wind, impact the ability to collect air samples and relate emissions to specific vehicles. Collecting meteorological data and incorporating it into diagnostic analyses will allow REMD users to evaluate local, micrometeorological impacts to determine how weather affects the system's ability to capture plumes.

High Emitter Detection

Concurrent testing and continued deployments will help refine the high emitter detection algorithm for continued development of flagging techniques that could be utilized as part of any REMD component. For the purposes of this report's analysis, staff looked at the potential of utilizing a "top five percent" high emitter threshold for purposes of flagging potential high emitters. Using a simplistic "top five percent" screening approach would have resulted in some vehicles without a MIL-related issue being identified as a potential high emitter. And although the utilization of such a screening criteria would flag some MIL-on vehicles, it would result in others going unidentified. Although a small data set, such findings highlight that a more robust screening methodology would likely be more effective when incorporating REMD into a future HD I/M program as a potential screening tool.

Conclusion

The efforts in this chapter demonstrated that REMD, including PEAQs, are viable screening tools for the HD I/M program. In addition, the findings listed above will help CARB improve the various components of REMD networks. CARB will continue to develop the high emitter requirements to minimize flagging compliant vehicles (i.e., those without a detectable need for emission-related repairs), while identifying non-compliant vehicles for additional testing. These efforts will help reduce frustration from compliant regulated entities, build trust in the program, and improve emissions reductions all at the same time. CARB staff continues to enhance high emitter screening criteria and are assessing potential methods beyond a simple "top five percent" methodology. As more data is collected prior to the effective date of a future HD I/M program, REMD thresholds and decision support tools will continue to improve and help validate more robust screening criteria. Although more work is to be done prior to implementing the HD I/M program, the pilots have demonstrated the potential for both REMDs and OBD/opacity compliance tests to be used together in a comprehensive HD I/M program.

Chapter 6 San Joaquin Valley Pilot Repair Assistance Effort

Introduction

As discussed in previous chapters of this report, repairs to HDVs to get into compliance with the program may be costly, potentially averaging on the order of about $2,000. Due to this cost, such repairs may be difficult for some fleets, especially for smaller fleets with less financial flexibility. It is in this context that CARB performed studies as to whether a repair assistance program could fit without the constructs of a future HD I/M program. Also, the studies looked into how such a program could look.

CARB funded a one million dollar ($1 million) Grant Agreement with the San Joaquin Valley Air Pollution Control District (APCD) to administer a Heavy-Duty Vehicle Repair Program Pilot Project which offered financial assistance to small fleet truck owners and operators for emissions system related repairs. The overall goal of the Pilot Project was to determine whether a heavy-duty repair assistance program could be implemented alongside a future heavy-duty vehicle inspection and maintenance program. Additional information related to common emissions-related repairs and costs associated with the project were also gathered. As part of the tasks set forth within the Grant Agreement, the District developed program guidelines, applications, and participant surveys. The District entered into agreements with several HDV repair shops in the San Joaquin Valley to conduct repairs in the program. This chapter provides a summary of the activities that were performed by the San Joaquin Valley District. The full report provides more details and can be found in Supplemental Chapter C.

Project Description

The Grant Agreement designated $850,000 for repair costs, up to $100,000 for project implementation and $50,000 for administrative costs. During the course of the project, the District issued vouchers for 156 repairs. Each repair was classified into one of nine emissions categories (Table 6-1). There were 131 trucks repaired during the pilot, including 15 trucks that went through the program two times and five trucks returned three times. Trucks that went through the program more than once received vouchers for different eligible repairs that occurred during different visits to the repair shop. Ninety-five percent of the trucks were Class 8 vehicles (33,001+ GVWR), with a majority having an engine mode year between 2013 and 2017.

Table 6-1. List of eligible emissions categories.

EMISSIONS CATEGORY	DESCRIPTION
FUEL INJECTION SYSTEM	Injectors, wiring, fuel pumps, regulators, etc.
EXHAUST GAS RECIRCULATION	EGR valve, cooler, controls
TURBO CHARGER	Turbo Charger & Charge Air Cooler
COMPUTER SYSTEM	Computers, modules, wiring, connectors, lights
DIESEL PARTICULATE FILTER	Filter, regeneration system, monitoring system, lights
CATALYST (SCR[1])	Catalysts, DEF[3] dosing system, monitoring system, lights
CATALYST (TWC[2])	Catalysts, monitoring system, lights
SWITCHES / SENSORS	Sensors for oxygen, air flow, temperature, pressure, etc.
OTHER EMISSION CONTROLS	Intake / exhaust manifolds, valve adjustment, air filter, crankcase controls

[1] Selective Catalytic Reduction (typically used with diesel)

[2] Three-way catalyst (typically used with natural gas / gasoline)

[3] Diesel Exhaust Fluid

Heavy-duty repair shops participating in the pilot had to meet the following conditions:

- Based within the San Joaquin Valley APCD boundaries;
- Be certified by engine manufacturer(s) to perform repairs;
- Have the ability to provide itemized estimates and invoices with labor, parts costs, and applicable OBD codes;

- Provide an itemized invoice that documented the approach used to diagnose necessary repairs and document the time and cost of each performed repair; and
- Enter into an Agreement with the District to participate in the program.

As the project administrator, the District was responsible for determining vehicle, participant, and repair eligibility; selecting repair shops and implementing a process in which the repairs were diagnosed, conducted, and reimbursed; surveying and documenting the participants' satisfaction with and acceptance of the vehicle repairs; and evaluating the feasibility of implementing a large scale program. Additionally, the District was responsible for meeting with CARB's Project Liaison on a regular basis to provide status updates; description of any difficulties encountered, project milestones or deliverables; and notification of pending disbursement requests.

Results

Table 6-2 lists these emissions-related repairs by category and by repair shop. Of the eligible applications submitted, exactly half had the DPF system circled, 46% of all the applications contained an invoice with a type of sensor or switch in need of repair, while 28% contained Injection System repairs. The Catalyst (i.e., SCR) and the Turbocharger systems were addressed in 21% of all pilot project repairs. Repairs associated with the EGR system represented 18% of the total applications. The District concluded that some of the less common emissions systems repaired were in the Other Computer System category and Emission Control System category with their respective percentages of 13% and 10%. Lastly, the District found that there were no repairs associated with the Catalyst (OC, TWC) category. This category contained Catalyst components such as monitoring and warning lights which were not displayed on any service invoice sent in for the program.

Table 6-2. Number of approved repairs in each category, broken down by repair shop.

EMISSIONS CATEGORY	VALLEY TRUCK REPAIR	RDM DIESEL	MYERS DIESEL	% OF TOTAL
INJECTION SYSTEM	42	2	0	28%
EGR	25	2	1	18%
TURBO CHARGER	30	3	0	21%

EMISSIONS CATEGORY	VALLEY TRUCK REPAIR	RDM DIESEL	MYERS DIESEL	% OF TOTAL
COMPUTER SYSTEM	13	0	0	8%
DPF	70	6	2	50%
SCR	29	1	3	21%
SENSORS / SWITCHES	62	5	5	46%
OTHER	14	0	1	10%
TOTAL VEHICLES AT SHOP	141	7	8	

Analysis

Of note, the average costs of repairs during this repair assistance program were substantially higher than the average projected repairs costs for a future HD I/M program on the whole. Although these costs seem to contradict each other on the surface, such a result is not unsurprising. Considering there is no HD I/M program currently being implemented that effectively enforces vehicles to maintain their emissions controls, a large incentive (i.e., large cost savings) would be needed to bring owners into a study where they are showing government entities like CARB their vehicles have emissions-related issues. Furthermore, such a study also requires an additional administrative burden on the fleets themselves beyond what would be experienced if they did not participate in the study. Thus, it is expected that a study like this has a higher expectation to bring in vehicles in need of extensive repairs, whereas smaller, less expensive repairs would not be worth the trouble for owners to go through the extra hoops in making the repairs. Therefore, it would be expected that a repair assistance program, in general, would see higher overall repair costs relative to the average even if implemented in coordination with the HD I/M program. Such an expectation is consistent with repair cost trends seen in BAR’s LD smog check program as well relative to repairs that apply for state assistance.

Although the repair assistance program was successful in repairing vehicles overall, many hurdles exist to implement such a program. Noted in the results was that a $1 million investment resulted in only 156 vehicle repairs. Thus, a substantial monetary investment would be needed to support a statewide repair assistance program. Furthermore, the District did face several challenges when administering the program, and it is expected that similar challenges would exist implementing such a program statewide. As one example highlight in the District's report, several of the contracts with repair shops had to be amended during the course of the project, emphasizing the need for flexibility when implementing such a program. Although feasible on a small-scale effort like this study, implementing on a similar basis for a statewide effort may be increasingly administratively burdensome. Another issue highlighted in the District's report was that not all of the contracted shops submitted any repair requests. This suggests that future programs should recruit more repair shops than are desired in the final program, to account for those who (for whatever reason) do not end up actively participating.

Staff at the District found that one of the most challenging aspects of the program was to determine repair eligibility and recommend flexibility for this determination in a future program. Many eligibility determinations were not straightforward and required a District or CARB expert to reach out for further clarification and analysis. Such case-by-case determinations could become increasingly burdensome on a statewide basis and maintaining such a level of flexibility may not be practical. Emissions systems on heavy-duty trucks are complex and establishing standards for writing up repair requests and determining which repairs should qualify for a program such as this could be challenging. Exacerbating this challenge is the fact that, unlike light-duty repair requirements that are governed by the Automotive Repair Act, there are no established standards for writing up repair orders in the HD repair industry, which contributes to the challenge of evaluating repair requests for eligibility. If CARB were to establish a heavy-duty repair assistance program, the District recommends that clear guidelines for determining who qualifies for assistance and the dollar limits of assistance could be received, as well as setting minimum standards for heavy-duty repair facilities and for technician experience.

It is also worth noting that the HD I/M program focuses on commercial entities and businesses, a fundamental difference relative to the LD smog check program, which applies to private citizens. Also, with the Governors directive to transition the California fleet away from combustion as specified in EO-N-79-20 (Office of California Governor, 2020b), it could be difficult to justify using taxpayer funding to support a program to prolong the life of diesel combustion vehicles owned by commercial businesses who may have failed to maintain them properly. Consideration should be given relative to whether it is better in the State's interest to support the repair of combustion vehicles versus further supporting the transition to cleaner zero-emission technologies.

Conclusions

This project demonstrated a small-scale HDV Repair Program in the San Joaquin Valley. CARB provided the financial backing for the program, while the San Joaquin Valley Air Quality Management District administered the program. The District collected pre- and post-repair surveys and performed 156 repairs with the $1 million dollars allocated for this study. Although the study demonstrated that a repair assistance program could be feasible alongside the future HD I/M program, many hurdles would need to be overcome to implement such a program on a statewide scale.

Chapter 7 CARB In-House HD Repair Durability Study

Introduction

In order for the HD I/M program to be successful and attain its emission reduction goals, the following prerequisites must be achieved:

1. The program must require malfunctioning, high emitting vehicles currently on California's roads to be repaired;
2. The repairs must correct the problems causing the high emissions and reduce the vehicles' emissions.

CARB staff performed CARB In-House HD Repair and Repair Durability Study to pilot test how successfully seriously malfunctioning HDVs can be repaired and to observe how OBD fault codes can be used to help diagnose and repair HD vehicles. As part of the study, staff also sought to recapture the vehicles months to years after repair to observe how long effective the repairs were at keeping emissions low over time.

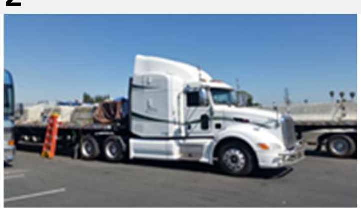
Because the study involved locating severely malfunctioning trucks and convincing their owners to allow their vehicles to be used in a State research project, the study also gave CARB staff an opportunity to interact with owners of malfunctioning trucks. In talking with these vehicle owners, CARB staff was able to better understand some issues that owners mentioned can potentially make it challenging for them to keep their trucks well maintained.

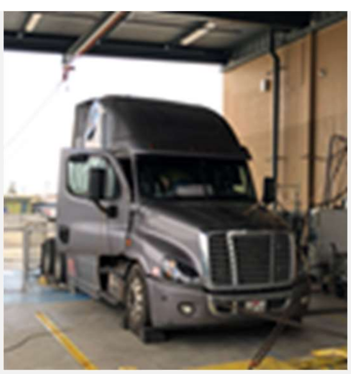
Further detail on the study design, test procedures and test cycles used for the study is provided in Supplemental Chapter D. Supplemental Chapter D also includes photos of the vehicles repaired.

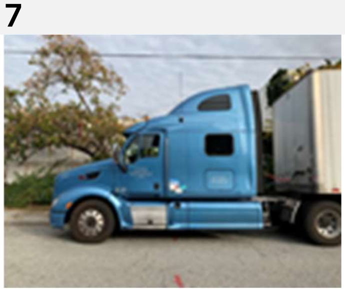
Vehicles Recruited, Defects Found, Repairs Conducted

Table 7-1 summarizes the characteristics of the vehicles recruited for the study and describes the HD OBD fault codes for each as well as the repairs performed.

Table 7-1. Summary of repairs made to HDVs.

NO.	TRUCK MY-MAKE-MODEL	ENGINE MY-MAKE-MODEL
1	**2012 Kenworth T800**	**2011 Cummins ISX-15**
	**Diagnostics / HD OBD codes:** • Engine Management Diagnostics (EMD+) No HD OBD, No MIL on • Dynamic Engine System Analysis (DESA) test results by Cummins dealer: – Diesel Oxidation Catalyst (DOC) Efficiency Fail – SCR Efficiency Fail	**Repairs:** DOC, SCR, NOx sensor
	1st Recapture	1 year after repair
	2nd Recapture	3 years after repair
2	**2013 Peterbilt 386 Series**	**2013 Cummins ISX-15**
	**Diagnostics / HD OBD codes:** • 1139, 1141, 1142, 1143, 1144, 1145: Injector Solenoid Driver Cylinder 1-6 Mechanical system not responding or out of adjustment • 3936: Aftertreatment 1 SCR Intermediate NH3 Sensor - Bad intelligent device or component • 3714: Engine Protection Torque Derate Condition Exists	**Repairs:** Cylinder Heads, 6 Fuel Injectors, Camshaft, DEF doser, doser gasket Coolant Leaking to fuel system repairs
	1st Recapture • 3714: Engine Protection Torque Derate Condition Exists	Diesel Dosing valve

NO.	TRUCK MY-MAKE-MODEL	ENGINE MY-MAKE-MODEL
	• 3568: Aftertreatment 1 Diesel Exhaust Fluid Dosing Valve 1 – Mechanical System Not Responding or Out of Adjustment	
3	**2016 Freightliner Cascadia 125**	**2015 DDC DD-15**
	**Diagnostics / HD OBD codes:** • 4364: SCR Conversion Efficiency 3364: DEF Tank Quality 1214: Aftertreatment 1 Outlet NOx • 3226: outlet NOx sensor	**Repairs:** ECU Reflush NOx sensors One-box (SCR+DOC) Radiator
4	**2014 Freightliner Cascadia**	**2013 DDC DD-15**
	**Diagnostics / HD OBD codes:** • Engine derated during PEMS testing • 5246: SCR Operator Inducement Severity • 3364: DEF Tank Quality 4364: SCR Conversion Efficiency	**Repairs:** 2 NOx sensors VPOD (Variable Pressure Output Device) DPF ACM (Aftertreatment Control Modules) Air brake valves
5	**2015 Freightliner Cascadia 125**	**2014 DDC DD-15**
	**Diagnostics / HD OBD codes:** Engine derated after major repairs • 3226: Aftertreatment Outlet NOx 1 • 5246: SCR Operator Inducement Severity • 4364: SCR Conversion Efficiency • 3364: DEF Tank Quality	**Repairs:** DPF NOx sensors One-box (SCR &DOC)
6	**2015 Kenworth T680**	**2013 Cummins ISX-15 425ST**

NO.	TRUCK MY-MAKE-MODEL	ENGINE MY-MAKE-MODEL
	**Diagnostics / HD OBD codes:** • 101: Engine Crankcase Pressure 1 • 81: Aftertreatment 1 DPF intake Pressure • 3720:Aftertreatment 1 DPF ash load percent data logger shows high ΔP >11 kPa • 81.16: Aftertreatment DPF system active regeneration occurring more frequently than intended as a result of a large amount of soot	**Repairs:** Crank Case Filter/sensor DPF
	1st Recapture • 3749: bad rear NOx sensor • 3226: Aftertreatment 1 Outlet NOx 1	NOx Sensor
	2nd Re-capture • 157: Engine Fuel 1 Injector Metering Rail 1 Pressure • 3464: Engine Throttle Actuator 1 Control Command	Fuel Injectors Crankcase pressure sensors In-frame kit Turbocharger DEF filter Bake DPF
	3rd Re-capture • 559: rail fuel pressure remains at least 100 Bar [1450 psi] less than commanded pressure	Fuel Lift Pump
7	**2014 Peterbilt 587**	**2013 Cummins ISX-15 525**
	**Diagnostics / HD OBD codes:** • Engine oil leak	**Repairs:** Predictive Maintenance Program DPF R/R twice within three years Turbocharger

Initial Improvement in Emissions

The study helps demonstrate that even vehicles with severely malfunctioning emission control systems could be repaired. The repairs succeeded in reducing both NOx and PM emissions, as summarized in Figure 7-1. On average, NOx and PM emissions were both reduced by 55 percent.

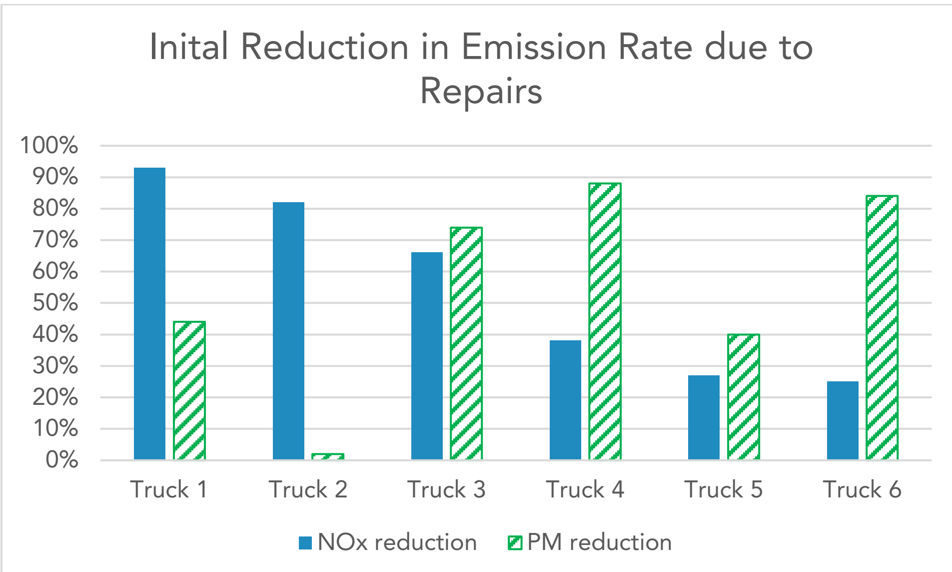


Figure 7-1. Initial reduction in NOx and PM emissions after repairs.

Repair Durability

It was difficult to recapture the trucks after repair, partially due to the covid pandemic. However, CARB staff successfully recaptured three trucks ranging from one month to three years after repair, Trucks 1, 2, and 6. As illustrated in Figure 7-2 and Figure 7-3 below, the initial repairs made were largely durable (i.e., emissions had not returned to their pre-repair state even after many months of operation on the road). Figure 7-2 below shows the NOx reductions after initial repair and then again after recapture. The NOx reductions after recapture were the same or slightly higher than upon initial repair, indicating the repairs achieved lasting NOx benefits. Figure 7-3 shows the PM reductions after initial repair and then again after recapture. Of the three trucks, only two, Truck 1 and 6 had PM-related repairs and so had initial PM reductions. For these two trucks, as for the NOx reductions, the PM reductions were lasting and apparent even after recapture.

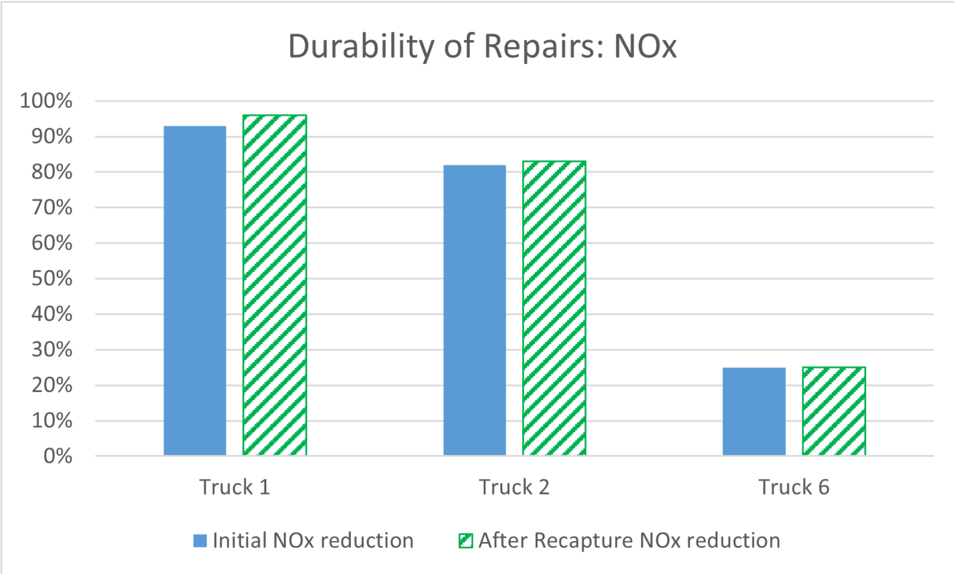


Figure 7-2. Comparison of NOx emissions reductions immediately after repair (blue) and after subsequent recapture (orange).

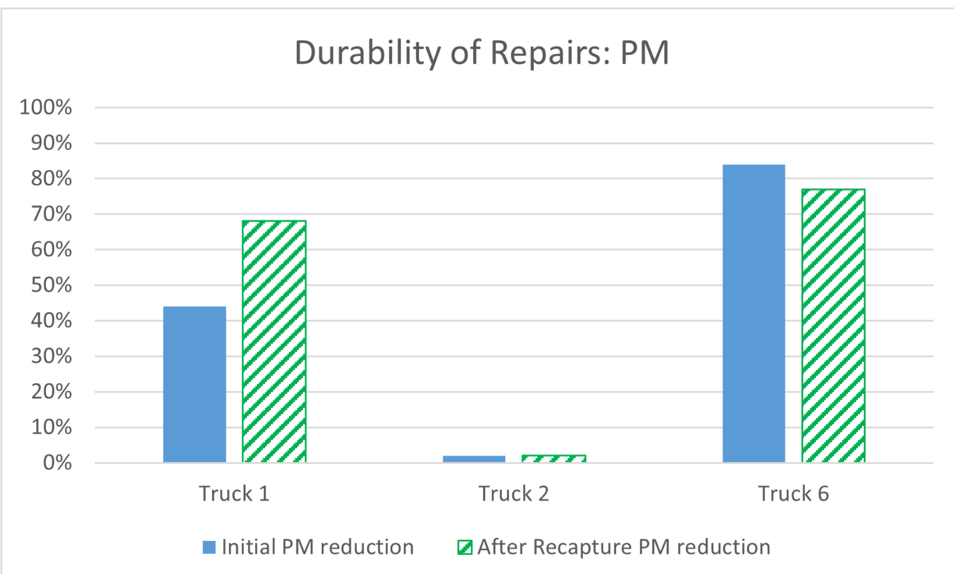


Figure 7-3. Comparison of PM emissions reductions immediately after repair (blue) and after subsequent recapture (orange).

Observations Regarding Emissions-Related Malfunctions

In the course of the study, CARB staff had the opportunity to interact with owners of malfunctioning trucks and talk with them regarding their experiences with emissions-related malfunctions. In talking with these vehicle owners, CARB staff was able to better understand issues that can make it challenging to keep trucks well maintained. CARB staff's observations from these conversations are summarized below:

1. Aftertreatment systems can be damaged by upstream engine problems that may be due to improper maintenance, tampering, and poor original engine manufacturer design. Unless these upstream engine problems are also diagnosed and repaired correctly, any repairs to the aftertreatment systems themselves will likely not be lasting. OEM-certified diagnostic technicians usually rely on OEM's diagnostic guidelines/repair trees to help with diagnosing issues with aftertreatment systems. It is also important for the technicians to understand the interaction between upstream engine issues and aftertreatment system issues, so they can quickly get to the root cause. For example, two testing trucks got a "DEF tank quality" fault code shortly after a DEF fluid refill. After replacing DEF fluid, NOx sensors, DEF filter, the fault code still existed. This occurred because the main issue was not addressed and was later found to be coolant leakage. Vaporized coolant had leaked from the radiator, and the moisture condensed on the NOx sensors by gravity which also explained why the newly replaced NOx sensors only lasted for a few weeks. Therefore, a thorough visual inspection to look over the entire aftertreatment systems, including the EGR all the way through to SCR was needed. Any visible leaks, excessive corrosion, or unusual wear may indicate a problem area.

2. Staff observed that when trucks were tested on the dynamometer with the MIL illuminated or certain mechanical problems, it could result in testing data being considered invalid. Emission measurement systems would automatically invalidate testing data when it detected an activated MIL or engine problem. Therefore, some trucks could not be tested on the dynamometer during this study. Staff found that, alternatively, data loggers and OBD scan tools can be used as a pre-screening tool to identify malmaintained trucks as part of this study and evaluate conversion efficiencies of aftertreatment devices. A real-time data streamer could continuously monitor a truck's emissions status such as DTCs, NOx conversion efficiency, and DPF's differential pressure changes.

3. Diagnosing through the repair tree can be difficult at times. Checking for previous trouble codes and looking at the previous repair history can provide additional direction beyond looking at the current vehicle OBD fault codes when assessing where to start a repair. Staff observed some situations where multiple fault codes made the initial repair diagnosis more difficult.

4. High repair cost and repair downtime were major concerns expressed to CARB staff by truck owners and operators during the course of this study. When the MIL is on or an engine is derated, truck drivers often use their own diagnostics scan tool and put the truck into a forced DPF regeneration to clear codes, and to remove derate associated problems without a visit to the OEM dealership. In addition, some truck owners and service providers prefer to repair the cheapest component first to see if it can solve the problem or to clear the fault codes and simply get back out on the road as quickly and cheaply as possible. However,

this process can end up costing the truck owner more time and money in the long run as the main repair issue is usually not addressed. Simply replacing the cheapest component and not looking holistically at the repair issue as a whole can result in the real maintenance issue not actually being addressed. This can result in the truck needing to come back to repair shop quickly with the same repair issue reoccurring, resulting in additional time in the repair shop spent troubleshooting the issue again, which leads to increased costs in the end.

Chapter 8 Conclusions

Senate Bill 210 directs CARB to conduct a pilot HD I/M program prior to taking an HD I/M regulatory proposal to the Board for potential adoption. In collaboration with stakeholders and other state agencies, CARB staff performed a pilot program to demonstrate technologies that could bring vehicles into the future HD I/M program. As part of this pilot testing effort, CARB and participating stakeholders pilot tested equipment that could be used to demonstrate compliance with the future HD I/M program, such as OBD collection and opacity measurement tools. Furthermore, the pilot program demonstrated potential vehicle monitoring equipment that could be used to enhance enforcement efforts and ensure more vehicle owners bring their vehicles into compliance with the future program. This included REMD technologies such as CARB's PEAQS system and instruments from leading remote sensing companies. ALPR cameras were also piloted to understand how to best optimize their use in the future HD I/M program.

The pilot effort to assess the feasibility of OBD data collection and compliance determination included collecting OBD data from real, in-use vehicles at several sites across California and other states. OBD data was collected through collaboration with two OBD device vendors. The effort verified that the OBD data CARB staff is considering to require as part of the HD I/M program could reliably be collected from HDVs and be used to determine emissions control compliance. OBD data collection was quick to perform and could be completed in under five minutes.

Both external and CARB-developed REMDs demonstrated effectiveness as stand-alone screening tools that could be used as part of the HD I/M program to identify potential high emitting vehicles. PEAQS, which was developed at CARB, has been deployed as both a mobile unit that can be moved to different locations based on future program needs and as an unattended, semi-permanent installation for long-term use. Unattended PEAQS deployments have screened over 238,000 vehicles at two CA sites for potential emissions control issues. During a two-week campaign in November 2020, PEAQS was deployed alongside two other commercial REMDs, and screened over 10,000 HDVs for potential emissions issues. Many HDVs were observed multiple times during this campaign, with NOx emissions being highly repeatable, including those from the highest emitters.

ALPR cameras were also tested as part of these pilot efforts, both through external contractor work and internal CARB work. Contractor field testing recorded vehicle capture rates of about 75 percent, however, further enhancements through CARB's internal PEAQS development efforts have improved vehicle capture rates to above 90 percent.

Beyond the specific SB210 pilot activities, several other efforts relevant to the development of the HD I/M program are also described in this report. First, contractors at

UC Riverside conducted a research study to assess potential design structures for a future HD I/M program and estimate the potential emissions benefits of a future program. The study recommended that a future HD I/M program incorporate an OBD based periodic testing approach complemented by an REMD component. Furthermore, the study estimated that an HD I/M program could reduce NOx emissions from the HD vehicle sector by about 50 to 75 percent.

Efforts were also undertaken by CARB and participating stakeholders to assess the potential repair costs that vehicle owners may incur to bring a vehicle back into compliance with a future HD I/M program and estimated average repair costs of about $2,000 per vehicle.

Another related project performed through a grant with the SJV air district assessed the potential of incorporating a repair assistance program as part of a future HD I/M program. Although feasible in the small-scale effort that was performed within the SJV region, this project identified several obstacles that could make a statewide repair assistance program difficult to implement.

Finally, CARB staff initiated an internal vehicle repair study to assess whether repairs could successfully be performed on vehicles with heavily damaged emissions control systems. The project successfully demonstrated that durable repairs could be performed and these vehicles could be brought back into a compliant status.

Overall, the pilot program and accompanying work have successfully demonstrated technologies that can be used as part of a future HD I/M program. Based on these results, CARB staff concludes an HD I/M program based on periodic OBD and opacity vehicle compliance tests is feasible. Furthermore, REMD systems can be used as an auxiliary mechanism to enhance compliance with a periodic testing program. Additional testing and research into all of these technologies will continue prior to the implementation of a future HD I/M program to further optimize their use in California’s HD I/M program, which will help ensure the future program brings as many vehicles into compliance as possible and is implemented smoothly and successfully.

Supplemental Chapter A

Final Report, Contact 15RD001

"Heavy-duty On-Road Vehicle Inspection and Maintenance Program"

Supplemental Chapter B

Final Report, Contract 18MSC001

"Heavy-Duty On-Board Diagnostic Data Collection Demonstration and Repair Data Collection Study"

Supplemental Chapter C

Final Report

Heavy-Duty Vehicle Repair Program Pilot Project

Supplemental Chapter D

Additional Information on CARB Repair Durability Study