Application of OBD equipment for inspection of heavy trucks

TEKNOLOGISK
INSTITUT

TEKNOLOGISK
INSTITUT

Application of OBD equipment for inspection of heavy trucks

Færdselsstyrelsen
Sorsigvej 35
6760 Ribe

Made by
Teknologisk Institut
Kongsvang Allé 29
8000 Aarhus C
Transport og Elektriske Systemer

In cooperation with
2M-Teknik

2M-Teknik

5. April 2021
Author: Kim Winther

Contents

1. Danish resume (dansk resume)

Denne rapport er udført for Færdselsstyrelsen som led i anden fase af regeringens indsats mod snyd med lastbilers NO_X-begrænsende udstyr. Om første fase se kildehenvisning [1].

Rapporten beskriver anvendelsen af OBD (On-Board-Diagnostics) som en metode til at afklare, om det emissionsbegrænsende udstyr på en lastbil er virksomt eller ej.

Udviklingen af metoden baseres dels på en overordnet gennemgang af OBD-systemets funktionalitet og dels på test af 15 forskellige lastbiler med og uden fejl I det emissionsbegrænsende udstyr. Nogle af lastbilerne er bevidst blevet forsynet med snydesoftware eller fysiske fejl, for at undersøge, hvorledes dette kan afsløres.

Baseret på disse erfaringer udvikles en trin-for-trin metode, som kombinerer OBD-systemets funktionalitet med en avanceret diagnosetester samt en række tjekpunkter, som tilsammen indikerer om en lastbil har et funktionelt emissionsbegrænsende system.

Resultatet viser, at manipulerede eller defekte emissionssystemer med stor sikkerhed kan afsløres på denne måde. Der kan dog også optræde en række tilstande, som kan understøtte en mistanke, men som ikke i sig selv er bevis for, at systemet er uvirksomt. Derfor er operatørens tolkning af dataene også en central del af metoden.

2. Introduction

This report investigates the possible use of On-Board Diagnostics (OBD) in heavy truck vehicle inspection to detect faulty emission systems and counteract illegal modifications done to the vehicle. A study of the OBD related regulations shows that current regulations do not offer such an inspection method. A suitable method is therefore developed as part of the project and included in this report. The robustness of the method is demonstrated on both fault-free, faulty, and illegally modified heavy trucks.

A PC with a professional OBD inspection tool is used to confirm that the vehicle has a working emission system and to assess if the software on the vehicle might have been tampered with. The system includes a Scan tool, a diagnostics tool, and a vehicle self-test mode for advanced users. These tools are discussed in detail within the report, alongside the important role of the operator.

Disclaimer:
This report has been produced by Danish Technological Institute and 2M-Teknik under a contract with the Danish Road Traffic Authority. The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the Danish Road Traffic Authority. The Danish Road Traffic Authority does not guarantee the accuracy of the data included in this study. Neither the Danish Road Traffic Authority nor any person acting on the Danish Road Traffic Authority´s behalf may be held responsible for the use that may be made of the information contained therein.

2.1. About On-Board Diagnostics (OBD)

As the name implies, OBD is an onboard part of the vehicle. This means that the functionality of OBD systems varies with vehicle type and age. Newer vehicles typically have more elaborate OBD functions and will deliver more useful information than older ones.

The OBD system is a completely autonomous system, which requires no human interaction. If errors are detected by the OBD-system, it will automatically assess the severity of each error and trigger the Malfunction Indicator Light (MIL) if needed. If the MIL is not lit or blinking, then the OBD system should not contain any critical information.

The OBD system is even capable of self-monitoring so that any problems occurring in the system itself, should be detected automatically. In general, OBD systems should therefore be quite reliable.

However, the OBD system can be tampered with, so that errors are not detected properly, or the MIL is not illuminated. Obviously, a tampered OBD system is not reliable and will not deliver true information. On the contrary, tampered OBD systems will often deliver falsified data. The self-monitoring ability of the OBD is also not reliable in this case.

In summary, OBD systems are generally reliable and do not require extra checks, unless the systems have actively been tampered with.

2.2. History

OBD was first introduced for heavy-duty vehicles in 2005 in Europe. It is usually designated European On-Board Diagnostics (EOBD) whereas the American version is called OBD-II.

OBD is used for light vehicle inspections in USA, but currently not in Europe (see chapter 2.3 for the US inspection method).

There are the following versions of European Heavy Duty OBD:

1. Stage I without NOx control (HD EOBD-I)
2. Stage I with NOx control (HD EOBD-I N)
3. Stage II without NOx control (HD EOBD-II)
4. Stage II with NOx control (HD EOBD-II N)
5. World-Wide Harmonized OBD (WWH OBD)

Stage I OBD is for EURO IV vehicles (before 2008). Stage II is for EURO V (before 2013).

Effective at the beginning of 2014, all newly registered heavy-duty vehicles in the EU must be diagnosable via World-wide harmonized OBD (WWH-OBD).

Worldwide harmonized OBD consolidates the whole range of OBD specifications for cars and commercial vehicles to create one regulation valid worldwide [2].

2.3. Method used in USA

An official OBD II emissions test in USA [3] consists of three parts:

1. An inspector checks to see if the MIL light comes on when the key is turned on. If the light does not come on, the vehicle fails the bulb check.
2. A scanner is plugged into the diagnostic link connector (DLC), and the system is checked for monitor readiness. If more than the allowed number of monitors are not ready, the vehicle is rejected and asked to come back later after it has been driven sufficiently to set the readiness flags. The owner then must drive a certain distance before the next test.
    i. The scanner also checks the status of the MIL (is it on or off?) and downloads any fault codes that may be present.
    ii. If the MIL is on and there are any OBD II codes present, the vehicle fails the test and must be repaired.
    iii. The vehicle also fails if the DLC is missing, has been tampered with or fails to provide any data.
3. As a final system check, the scanner is used to command the MIL on to verify it is taking commands from the onboard computer.

This method is designed for passenger cars. Part 1 and 2 are also suitable for European trucks and will be used as part of our method. However, part 3 is not possible on the trucks we investigated, so it will be left out.

The US method only uses basic OBD tools whereas the method proposed in this report will incorporate more advanced diagnostics tools.

2.4. Approach used in this report

To develop a method that uses OBD in heavy truck vehicle inspection to determine if the emission reduction system on the truck is functional or not, the following approach has been applied.

The method is developed to be used with any advanced OBD diagnostics tool. The system currently chosen by the Danish Road Traffic Authority is the Wabco-Würth OBD-diagnosis equipment W.EASY BOX 2.0 (Figure 1). Other systems can be used as well.

Figure 1 – Wabco-Würth W.EASY BOX 20.0

During the development of the method a BOSCH KTS Truck OBD tool has also been used for reference (Figure 2).

Figure 2 – BOSCH KTS Truck OBD tool

In the development of the method the following parameters from the OBD system have initially been in focus:

- Software version
- Date for software changes
- Date for last reset of DTC (Diagnostic trouble code)

- Presence of SCR (Selective Catalytic Reduction), EGR (Exhaust gas recirculation) and DPF (Diesel particulate filter) systems on the list of components
- Signals from sensors coupled to NO_X and particles.
- Error messages (DTC's) from physical errors e.g., disconnected urea dosing

To assess which of the parameter(s) give the indication of malfunction or manipulation 15 different trucks have been investigated both with and without manipulation (see Chapter 6).

The manipulation covers both software and physical disconnection of emission systems. The results from the testing of the vehicles are then used to assess the robustness of the method.

The final method has then been described and can be found in Chapter 5.

3. OBD-systems in relation to emissions reduction equipment

This section introduces OBD on heavy duty vehicles, from a European perspective, and specifies OBD-parameters that might reveal errors on the emission systems and potentially turn on the malfunction indicator lamp (MIL).

3.1. Requirements

Regarding access to OBD data communication, European-based OBD systems should conform to either ISO 15765 or SAE J1939. In present time, it is almost entirely based on CAN-bus (ISO 15765). CAN-bus, or Controller Area Network bus, is the standard though which the vehicle devices communicate.

Below is a short summary of OBD requirements for European heavy trucks [2].

The Stage I OBD system may monitor thresholds values as follows:

- Reduction in the efficiency of the de-NO_X system, with respect to NO_X
- Reduction in the efficiency of the Diesel Particulate Filter (DPF), with respect to PM
- Reduction in the efficiency of the combined de-NO_X + DPF, with respect to both NO_X and PM.
- If any type of catalyst, e.g., a Diesel Oxidation Catalyst (DOC) is removed

Stage I threshold values are NO_X 7000 mg/kWh and PM 100 mg/kWh. As an alternative to using these, however, Stage I OBD system may also monitor for major failure of the following components:

- Other catalysts, e.g., a DOC
- De-NO_X system (sensors and actuators, dosing control unit, clogged nozzle, pump failure)
- DPF system (sensors and actuators)
- Electronic components of fuel injection systems
- Exhaust gas recirculation (EGR) systems
- Sensors and controllers for air mass flow and temperature
- Sensors and controllers for boost pressure and inlet manifold
- Electrical disconnection (circuit integrity)

- Availability, quality, and consumption and dosing of reagent (e.g., urea)

Stage II OBD maintains the threshold values as in Stage I but added the following requirements:

- Monitoring of the electronic interface between the Engine Control Unit (ECU) and other electrical systems for continuity.
- Adoption of a standardized OBD systems across manufacturers and open access to repair information, so that vehicles can be serviced in any workshop.

Euro VI WWH-OBD introduced many more requirements:

- More stringent OBD threshold values and type approval based on the World Harmonized Test Cycle (WHTC)
- Adoption of In-Use Performance Ratios (IUPRs)
- Additional monitoring requirements for EGR flow, EGR cooling system, boost (turbo and superchargers) and fuel injection systems.
- Classification of error codes are classified into Severity Classes A, B1, B2 and C, indicating the severity of a failure about its effect on exhaust emissions quality (see section 3.2.5).

WWH-OBD is based on Global Technical Regulation (GTR) No. 5 and ISO (International Organization for Standardization) 27145.

EURO VI threshold values are NO_X 1200 mg/kWh and PM 25 mg/kWh. These cannot be measured on the vehicle but serve only as guidelines for the manufacturer in determining the severity of a fault.

3.2. Functions

This section introduces the generic functions found on most OBD systems.

3.2.1. The Malfunction Indicator Lamp (MIL)

The Malfunction Indicator Lamp (Figure 3) is the most important part of the OBD system. The MIL lights up whenever a critical fault in the emission system is detected. At key-on the MIL shall light up for a bulb check and then shut off again shortly after engine start.

Figure 3 Example of a Malfunction Indicator Lamp (MIL)

The OBD system has a cumulative continuous-MI (Malfunction Indicator) counter to record the cumulative number of hours during which the engine has been operated over its lifetime, while the continuous MIL is active.

3.2.2. SCR warning system

SCR (Selective Catalytic Reduction) is a type of catalyst used for NOx reduction. The name tends to be synonymous with Urea-, AdBlue-, DEF-, de-NO_X or NOx-control system.

The objective of the SCR warning system is to prevent the occurrence of SCR system failures owing to human interaction or lack thereof. Because the OBD system also monitors urea quantity and quality, the SCR warning system and OBD requirements tend to be confused; the SCR requirements utilize a subset of signals from the OBD system to take actions that go well beyond what the OBD is designed for, such as reducing the torque or immobilizing the vehicle.

A lit SCR warning lamp (Figure 4) is a critical failure.

Figure 4 Example of a SCR warning lamp

3.2.3. PID's

PIDs (Parameter Identifiers) are codes used to request data from an OBD system. SAE standard J/1979 (or SAE J/1939) defines many PID's (see Figure 5). There are roughly 166 standard PID's defined.

PID's er useful for inspection purposes because they show real time signals from dozens of sensors on the vehicle, including e.g., NO_X sensors.

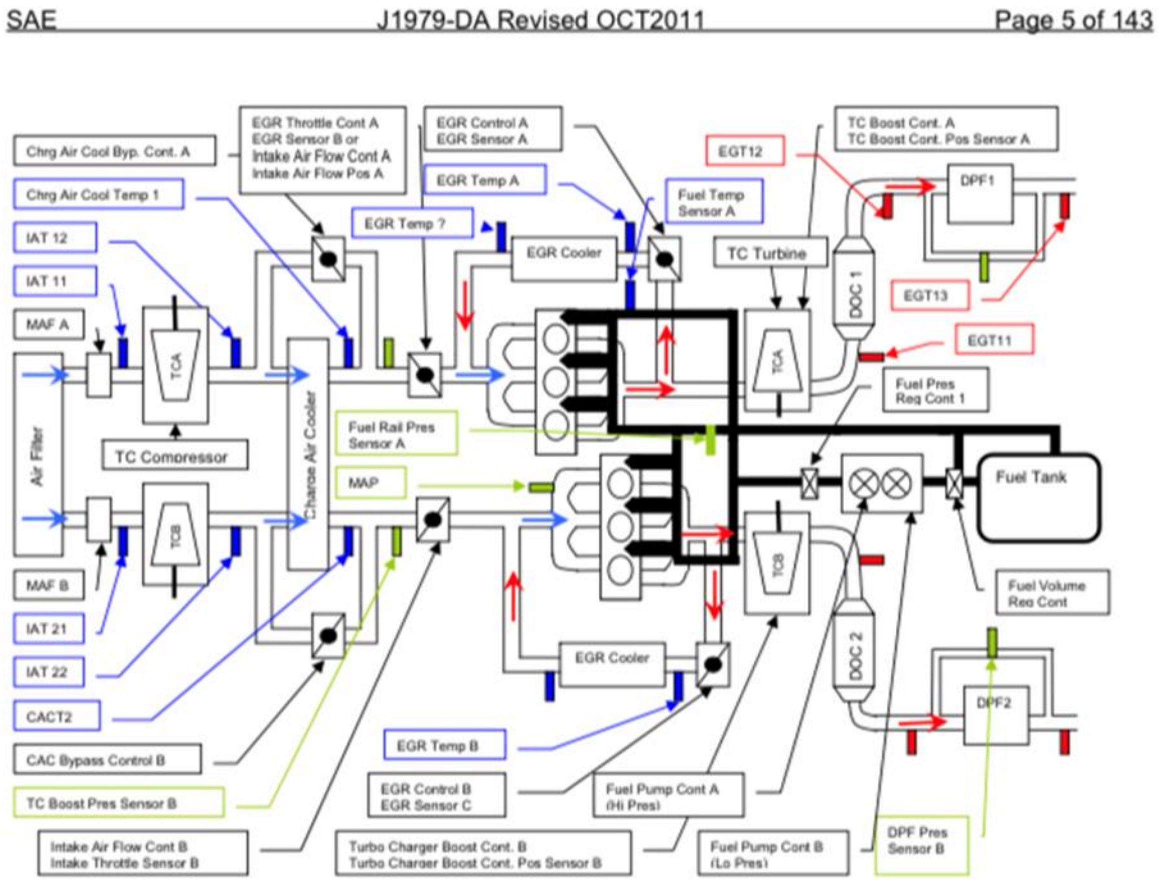

Figure 5 Examples of emission related PID's found on modern OBD systems.

PID values are delivered either as instantaneous (Data Stream) or as "critical" values detected along with an error occurrence (Freeze-Frame). The Data Stream is also known as a Data List.

Mandatory PID's [3] are only a small subset which are not sufficient for inspection. Vehicles typically offer many more, but it also depends on the Scan tool (4.2) that is used for the inspection.

Software version and CVN (Calibration Verification Number) are easily shown as PID's but cannot be verified without the help of an Original Equipment Manufacturers (OEM) workshop.

The same is true for the software date. Even if the software was recently updated, this does not indicate fraud as it may have been done as part of the normal maintenance.

3.2.4. Readiness monitors

Readiness monitors are also known as Emission Monitors since they are used to self-test the emissions control system of the vehicle.

Relevant types of readiness monitors for heavy diesel vehicles are:

- NOx/SCR Aftertreatment system
- Exhaust gas sensor
- PM Filter or DPF
- EGR system
- NMHC Catalyst (ammonia slip catalyst)

Ideally all monitors read “Complete” or “Ready”. However, it may also read “Incomplete” or “Disabled” if the vehicle has not been able to perform the necessary self-test. This, however, does not automatically indicate a fault on the vehicle.

The most important thing is the presence of all systems. If a certain category e.g., SCR or DPF on a Euro VI vehicle is missing from the list it strongly suggests manipulation.

3.2.5. Diagnostic Trouble Codes

Diagnostic Trouble Codes (DTC’s) are error codes. There are several thousands of these error codes, and they are partially brand specific. The codes can be read with any common OBD Scan tool and further identified and analyzed by a more advanced diagnostics tool. An example of a DTC read in this project:

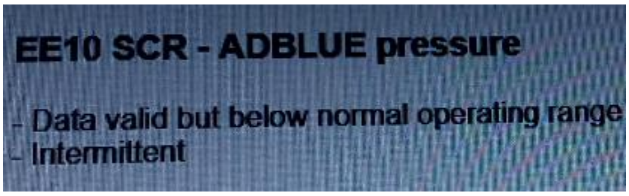

Figure 6 DTC found using an OBD diagnostics tool.

The codes can have the following states: Pending, Potential, Intermittent, Confirmed and Active, Stored, Permanent or Inactive.

A **pending** DTC means that an internal test cycle was not completed. It persists until the test cycle has been run successfully. A pending DTC is usually not a problem.

A **potential** DTC is a pending DTC which is not confirmed and active. This is usually no problem either.

Intermittent DTCs only occur occasionally and should not raise a big concern either.

Confirmed and Active DTC means that a malfunction has occurred enough times for it to be **Stored** in the fault memory of the vehicle. It does not necessarily indicate that the fault is present at the time of inspection.

Permanent DTC’s are also **Stored** and commands the MIL to turn on. These are serious faults.

Inactive DTC’s are DTC that were previously active but no longer is, indication that the function of the emissions system has been restored.

Physical errors, such as the removal of a sensor, disconnected urea dosing will most likely trigger a DTC. However, If the vehicle software has been tampered with, these faults may be camouflaged. So, the absence of DTC's in case of physical faults is a culprit.

A severe DTC will illuminate the MIL (se section 3.2.1), which should automatically result in rejection of the vehicle at vehicle inspection. Whether a malfunction is classified as severe or less is entirely up to the OBD itself to determine.

WWH-OBD [6] has four classes of malfunctions, A, B1, B2 and C based on the severity of each. Class 'A' malfunctions are the most severe and Class 'C' are the least severe.

Class A *are malfunctions where the OBD system itself reports that the threshold values (section 3.1) are being exceeded. The OBD system does not measure actual values in mg/kWh, so it is more of an assumption. This is obviously a serious case, because the vehicle will most likely need repair, but it also demonstrates that the OBD system is doing its job. Class A malfunction shall always light up the MIL.*

Class B1 *are malfunctions which may lead to emissions being too high. This may not trigger the MIL at once but should do so after 200 hours if the error was not corrected.*

Class B2 are *malfunctions which may lead to elevated, but not too high emissions. This may not trigger the MIL at all.*

Class C *are malfunctions which should not elevate the emissions beyond type approval limits. These may also trigger the MIL but if that does not happen, they should not be a big concern.*

The OBD system shall contain a B1 counter to record the number of hours during which the engine has operated while a less severe Class B1 malfunction is present, because the MIL shall only be lit if the error is persistent.

The severity classes cannot be read from a Scan tool. Thus, severity class cannot directly be used for inspection.

3.2.6. Modes

The older OBD versions (not WWH) read out the DTC's separate from their status in different OBD modes.

The function codes (operating modes) that the control unit uses, when the diagnostics connector is connected, are specified in the ISO 15031 standard.

There are ten modes of operation described in the OBD-II standard SAE J1979. They are as follows (the 0x prefix indicates a hexadecimal radix):

- 0x01. Show current data
- 0x02. Show freeze frame data
- 0x03. Show stored Diagnostic Trouble Codes
- 0x04. Clear Diagnostic Trouble Codes and stored values

- 0x05. Test results, oxygen sensor monitoring (non-CAN only)
- 0x06. Test results, other component/system monitoring (Test results, oxygen sensor monitoring for CAN only) 0x07. Show pending Diagnostic Trouble Codes (detected during current or last driving cycle)
- 0x08. Control operation of on-board component/system
- 0x09. Request vehicle information. Firmware versions (calibration identification) and a checksum to verify the authenticity of the firmware (calibration verification number).
- 0x0A. Permanent DTC's (Cleared DTC's)

WWH-OBD does not use the ten modes described above, but instead uses a much more elaborate system. The classification of modes is therefore not particularly relevant for the inspection of newer vehicles.

3.2.7. IUPR monitors

In-use performance ratio (IUPR) values are used by manufacturers primarily to determine the effectiveness of the OBD system in real driving compared to type approval conditions.

The OBD system must have the capability of tracking and recording IUPR data. Contrary to other OBD data, IUPR data cannot be used to draw conclusions concerning the roadworthiness of an individual vehicle. Therefore, IUPR monitors will not be discussed further in this report.

4. Inspection setup

This chapter describes the tools and human resources needed to carry out inspection via OBD as prescribed in this report.

It is crucial to keep in mind the interfaces between the vehicle (test object), the OBD tool(s) and the operator as well as knowing the capabilities and limitation of each part as shown on Figure 7.

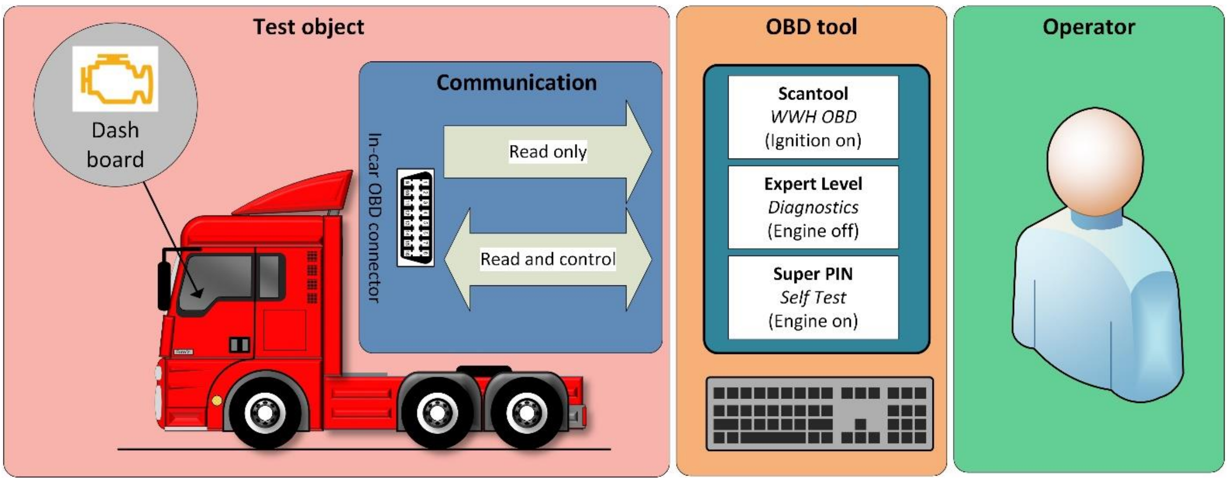

Figure 7 Inspection setup with tools and communication showed

We will now discuss the capabilities and limitations of each part.

4.1. The vehicle (test object)

The vehicle is what contains the entire OBD-system. The test object thus is testing itself as described in section 3.1. The only user interaction required is the observation of the Malfunction Indicator Lamp (See section 3.2.1).

The vehicle may also have a SCR warning system to alert the driver (see section 3.2.2). In that case, the warning light must not be lit.

A tampered OBD system will not automatically reveal that it has been tampered with. Warning lights will most likely be deactivated if such manipulation has occurred.

4.2. The OBD tool (Scan tool, diagnostics tool)

The OBD system has a standardised Diagnostic Link Connector (DLC), which provides a communication interface. This is commonly achieved with a Scan tool, which can be acquired at very low cost (<100 EUR). Communication is typically on-way which only allows readout of some generic data from the system.

A Scan tool can also be used to delete DTC's, but this will only affect pending DTC's. Active and Stored DTC's cannot be erased by clearing DTC's with a scan tool.

Scan tools are also known as OBD-readers, -scanner or -loggers. They are available as simple add-ons for smartphones etc.

In case of manipulation, common Scan tools are likely to read data that are falsified. Therefore, common scan tools are not sufficient tools for thorough inspection.

Modern high-performance diagnostic tools, also known as multi-brand testers, offer full support of the new WWH-OBD standard. The tools we used in this project are advanced multi-brand testers and are shown in section 2.4.

In addition to the common OBD functions, advanced diagnostic tools have an advanced mode (Expert mode) allowing for more comprehensive functions. These functions may be used to reveal data otherwise hidden. They can also remotely activate certain systems of the vehicle. They differ a lot in price and functionality, but a high-end diagnostic tool could cost about 3000 EURO.

Although the basic communication protocol is still OBD-based, and the same plug is used for interface, there are many vehicle specific functions and parameters beyond those of generic OBD.

High-end diagnostic tools contain lots of vehicle specific information on many brands and are almost comparable to the original manufacturer's vehicle specific test equipment. Original brand specific equipment is ultimately the best for any specific vehicle, but generic multi-brand testers are also recommendable.

The use of advanced diagnostic tools is discussed further in section 5.3

On top of diagnostics, some OBD tools offer advanced self-test functions, which is useful to reveal faults or illegal software manipulation (manipulation) that affects the emission reduction system.

Examples of professional OBD equipment with advanced diagnostics functions are Wabco-Würth and the Bosch KTS Truck, amongst others. The general difference between diagnostics and self-test is that the latter requires the engine to be running.

These functions shall be used with caution as they could ultimately harm the vehicle. For instance, a forced DPF regeneration at standstill could cause a vehicle to catch fire.

The use of advanced self-test functions is discussed further in section 5.4

4.3. The operator (inspector)

To determine if an emission system is truly functional or may have been tampered with, it is necessary for the operator to have knowledge about typical OBD parameters and their normal range of values, e.g., the normal temperature of a catalyst, normal levels of NOx, system pressures etc. The operator will need to know which parameters should be stable, under which circumstances and which ones should move dynamically with engine RPM.

The operator will also need to know which systems should be available on a vehicle e.g., if an EGR system should be present or not.

We therefore recommend that operators are trained properly in the use of advanced vehicle diagnosis and self-test functions.

5. Step-by-step inspection procedure

The final recommended procedure for inspection is shown in Figure 8. The procedure should be carried out in the order prescribed, because the latter parts are rather time consuming.

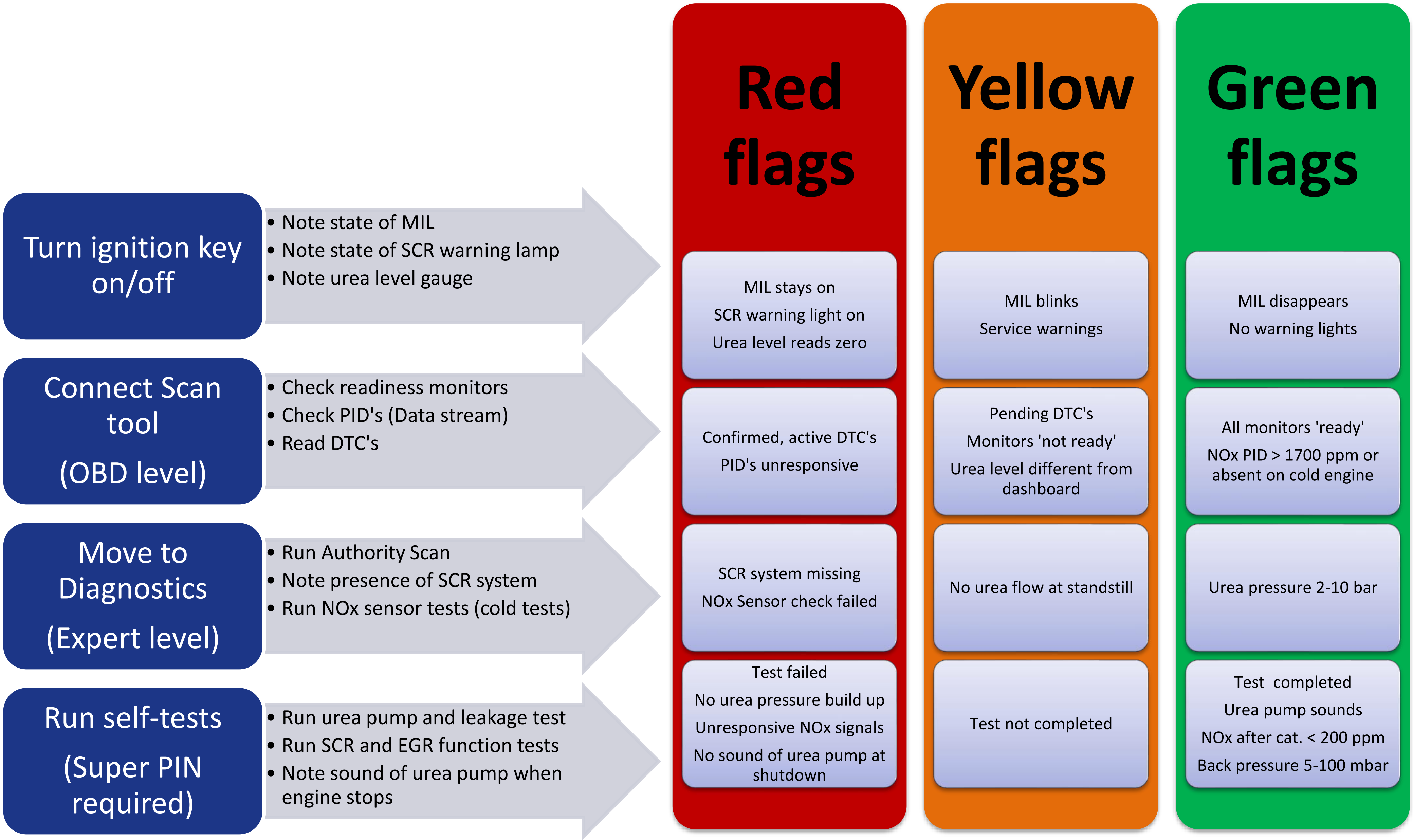

Figure 8 Step-by-step method for inspection via OBD

For each step, a red, yellow or green flag is assigned according to Figure 8.

Red flags: This is NOT normal and strongly indicates a malfunctioning system or illegal manipulation.
Yellow flags: This could be normal but should raise suspicion if occurring repeatedly.
Green flags: This is perfectly normal and indicates a properly functioning system.

5.1. Step 1 Turn ignition key on/off

This part uses only the vehicle itself. No additional tools are required.

1. Turn the key to the 'ON' position without starting the engine. If MIL does not light up for a bulb check, make a red flag.
2. Turn the engine on. If the MIL disappears, make a green flag. If the MIL blinks, make a yellow flag. If the MIL stays on for more than 10 seconds, make a red flag.
3. If a SCR warning lamp is lit, make a red flag.
4. As a final check, note the urea level gauge in the vehicle. If the gauge reads "0" make a red flag,

5.2. Step 2 Connect Scan tool (OBD level)

Any generic OBD tool could be used for this purpose as long as it is 24V compliant. However, the use of the Wabco-Würth has been pre-selected by the Danish Authorities and the focus will therefore be on the functions and menus available on this tool. The Wabco-Würth tool has both a generic OBD Scan tool and an advanced diagnostics tool built in. Users of Wabco-Würth or similar advanced OBD tools will not notice much difference between this step and the next.

Select vehicle using automatic VIN identification with the OBD connection to the vehicle established, and the ignition key in the ignition 'ON' position. The VIN can also be entered manually, or the vehicle chosen based on manufacturer, model, and model year.

After connecting to the OBD-vehicle you see the **EOBD start page.**

Look for Readiness Monitors, especially emission system, SCR/urea/AdBlue and DPF
Note DTC's if any (this can also be done in Step 3)
See Data lists (show PID's) this can also be done in Step 3.
Touch throttle to see if PID numerical values change

- DPF back pressure, if shown, shall respond to engine RPM
- NOx levels after SCR should be below 200 ppm.
- NOx ppm should be read only with a warm engine (10 minutes of driving). If cold values are shown these may be falsified and come from a fake sensor, also known as an emulator.
- SCR system should switch off below 210-280°C.
- SCR temperature should be above 210-280°C when operating.
- Urea flow rate / dosing level should be 1-5 kg/h but might require vehicle to be moving.

- Urea pump operating pressures should be 2-10 bar and drop to zero when engine cools off.
- Urea tank level should match both the gauge and the true level in the tank.

Note that Numeric values (PID's) may be wrongly scaled on generic OBD tools, so if a single value reads a strange number this does not automatically indicate a fault on the vehicle.

5.3. Step 3 Move to diagnostics (Expert level)

Any advanced multi-brand diagnostics tool can be used, but here we will focus on the Wabco-Würth.

On the Wabco-Würth tester, run the 'Authority Scan' feature. Authority scan detects the system status of all emission related components on the vehicle. This function is recommended because it automatically leaves out vehicle systems that are not relevant for emission inspection. It does not require Super PIN password like Step 4 does.

Run Authority Scan, Start, Continue (wait 5 minutes)
Check for SCR presence if not already found in Step 2
Click on DTC's if no sufficient data was obtained in Step 2
See Data lists (show PID's) if data stream from Step 2 was not sufficient.

- DPF back pressure, if shown, shall respond to engine RPM

Run NOx sensor test with engine OFF (10-15 min) if that test is available.

The NOx sensor self-test, if available, will electrically heat up the sensors and determine if they are functioning all right. This is convenient as it can be done with a cold engine. Access to available tests is shown in (Figure 9).

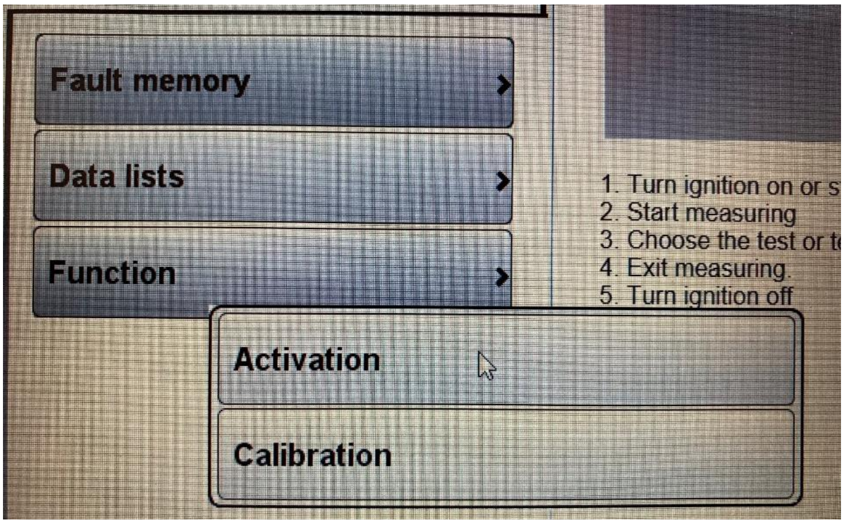

Figure 9 To see available tests, chose 'Activation' or 'Calibration' in the 'Function' menu.

DTC's are found in the Systems menu on the Wabco-Würth tester. In Step 3, as opposed to Step 2, these can be clicked upon to show more details about each DTC.

Remember that DTC's are fundamentally a sign of the OBD-system working properly. Only stored and confirmed DTC's should be a concern. As mentioned, there are thousands of DTC's depending on the vehicle type. Therefore, no complete list can be given. If the DTC's are not emission related, then they should not be a concern either. The Wabco-Würth tool automatically sorts the emission related codes from the rest with the 'Authority scan' feature.

Specific DTC's to watch for are:

- ACM/Emission system
- SCR/AdBlue/de-NOx system
- EGR system
- AdBlue/urea/reagent/reactant dosing system

It is quite common to see several DTC's and they should generally only raise a yellow flag. However, certain DTC's may suggest manipulation as shown in section 6.1.

5.4. Step 4 Run calibration/self-test (requires Super PIN)

This section requires an advanced multi-brand tool or a brand-specific OEM tool. This description, however, deals specifically with functions and menus found in the Wabco-Würth tool.

The test functions in the Wabco-Würth tool are similar to those found on brand-specific OEM testers. However, this is an approximation and therefore the features cannot be guaranteed to work 100% like the original software.

The tests generally require a Super PIN password, in which case the user will be prompted. Note that all tests are not available on all vehicles. The absence of a test menu does not indicate fault on the vehicle.

The Super PIN mode includes functions, which exceed the standard scope of use in Expert mode, such as the programming, configuration and adjustment of engine, chassis or brake parameters, the resetting and deletion of DTC's, engine control functions, as well as comfort and security settings.

The test procedures must be carried out according to the on-screen guidance texts. There is no written manual or other available instruction from Wabco-Würth.

Self-test procedures will effectively test the function of EGR and SCR systems and even command a regeneration of the DPF. The latter, however, is not recommended due to the risk of fire.

Activate Engine management, Function, Calibration…
Urea pump and leakage test (2 minutes)
Run urea metering amount test if available.
Run EGR function test if available (3 minutes)
Run SCR function test if available (25 minutes)

After the SCR function test, turn the engine ‘OFF’ and listen for the sound of the urea pump returning urea to the tank. If no sound is heard, make a red flag. If the sound is heard, make a green flag. Note that it does not rule out manipulation as seen in 6.1.22.

The urea pump and leakage test as well as the metering mount test (‘doseringsmængde’ in Danish) usually require Super PIN. The tests are activated as shown in Figure 10.

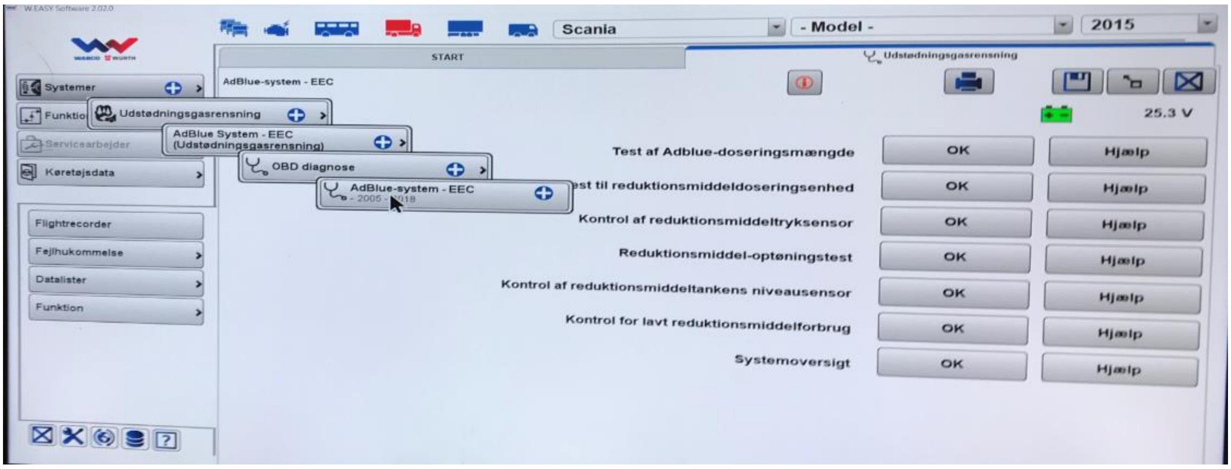

Figure 10 Urea (AdBlue) system test menu location (Danish language)

The sound of a pump switching on should be audible and urea pressure should rise when the pump is switched on as shown in Figure 11.

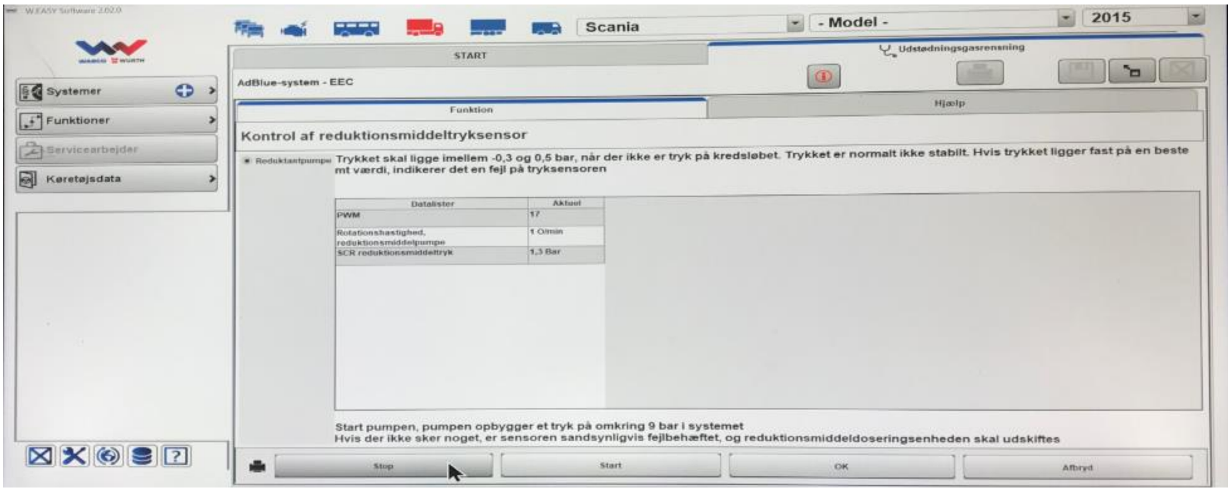

Figure 11 Urea (AdBlue) pump speed and system pressure (Danish language)

This can be done with a cold engine. The pressure expected to be built by the pump is in the range of 2-10 bar. In case of a malfunction or manipulation it is likely if no or very low pressure (~0,1 bar) is built by the pump.

The EGR test verifies the flow in the EGR system, which would usually be blocked in case of manipulation. The test is activated as shown in Figure 12.

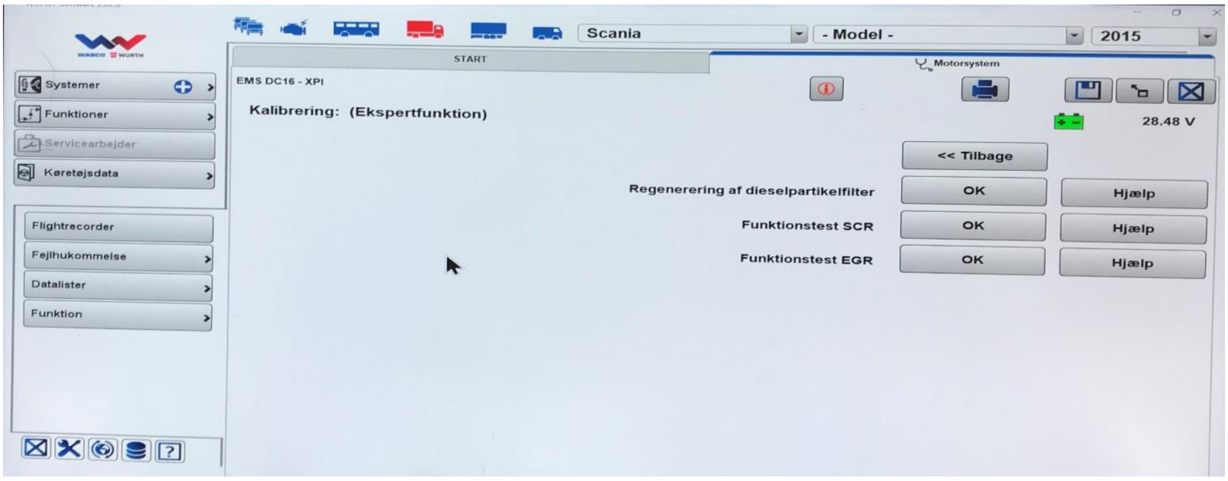

Figure 12 Overview menu for DPF, SCR and EGR function tests (Danish language)

The full SCR test requires Super PIN but can also be activated from the menu in Figure 12. This requires the Systems->Engine control unit to be activated first.

Forced regeneration of DPF can be activated the same way, but there is no point in completing the process as it is time consuming and potentially dangerous. The test for the DPF is sufficient as soon as the back pressure PID has been verified in Step 2 or 3.

6. Demonstration of the robustness of the method

A range of 15 trucks were sampled from a variety of manufacturers. This was done to understand how plausible it was to manipulate emission reduction systems for each brand of truck. Manipulated software was installed in some of the trucks, so that the plausibility of detection of the manipulation software could be studied. Manipulation of the physical hardware (connector removal) was also taken into use. All trucks were returned with their original software and hardware. The trucks are common and in use today. Test reports in Section 6.1 show the results.

6.1. Test reports

Test reports 6.1.1 to 6.1.11 were done in the phase of developing the method while the rest were done to verify the method. Items marked with "-" indicate that the test was not done. The latter test reports are following Test step 1-4 (from Figure 8) therefore more comprehensive and in line with the final inspection method.

6.1.1. Scania S510 brand new

Vehicle Test date Manipulation Method and tools used	Scania S510 (EURO VI) 20-01-21 No manipulation Bosch KTS Truck tool used on this vehicle. Older version of Würth tool tried but not functional due to missing truck module.	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No warnings	
Note urea level on dashboard	27%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	Supervision of NOx/SCR system not complete Supervision of DPF not complete	
Check PID's	Exhaust pressure = 1,011 bar Runtime with active MIL = 0 minutes Runtime since deletion of DTC's = 131 min. Voltage 24,64 V NOx = 0 ppm (engine off) Oxygen content = 20,26% (engine off) Engine runtime with SCR problem = 0 h	
Read DTC's	Emission related DTC's = 0	
Step 3: Move to diagnostics	Observations	
Run Authority scan	DPF back pressure = 0 ,014 bar (engine off) AdBlue pressure = 0 bar (engine off) AdBlue flow = 0 g/min (engine off)	
Note presence of SCR system	System present	
Run NOx sensor test	Test not available	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	System display shows complete SCR system with all components and all values present	
SCR and EGR function test	No EGR found on vehicle	
Note sound of urea pump	Pump sounds	
Conclusion	Vehicle is brand new and fully functional. Despite monitors 'not complete' and DTC's deleted recently there should be no doubt at all. The vehicle passes inspection.	

6.1.2. Volvo FH460 in standard trim

Vehicle Test date Manipulation Method and tools used	Volvo FH460 (EURO VI) 22-01-21 No manipulation Both Wabco-Würth and Bosch KTS Truck tool used	

Step 1: Ignition key on/off	Observations
Note state of MIL	Lamp test OK then off.
Note SCR warning lamp	No warnings
Note urea level on dashboard	24%
Step 2: Connect Scan tool	**Observations**
Check readiness monitors	ACM OK
Check PID's	Urea 24% DEF pressure 0 mbar AdBlue temperature 24 deg. C AdBlue demand 1.1 l/h Soot content 66%
Read DTC's	9 Faults not emission related
Step 3: Move to diagnostics	**Observations**
Run Authority scan	-
Note presence of SCR system	-
Run NOx sensor test	-
Step 4: Self-test (Super PIN)	**Observations**
Urea pump and leakage test	-
SCR and EGR function test	-
Note sound of urea pump	-
Conclusion	Vehicle OK

6.1.3. Volvo FH460 with bad wiring

Vehicle Test date Manipulation Method and tools used	Volvo FH460 (EURO VI) 22-01-21 Electrical connections to SCR module removed. Both Wabco-Würth and Bosch KTS Truck tool used	

Step 1: Ignition key on/off	Observations
Note state of MIL	-
Note SCR warning lamp	-
Note urea level on dashboard	-
Step 2: Connect Scan tool	**Observations**
Check readiness monitors	-
Check PID's	-
Read DTC's	U029D Lost Communication with NOx sensor "A" U029E Lost Communication with NOx sensor "B" U116F Lost communication with reductant control module P20F4 AdBlue consumption too low
Step 3: Move to diagnostics	**Observations**
Run Authority scan	-
Note presence of SCR system	-
Run NOx sensor test	-
Step 4: Self-test (Super PIN)	**Observations**
Urea pump and leakage test	-
SCR and EGR function test	-
Note sound of urea pump	-
Conclusion	Bad wiring detected from DTC's

6.1.4. Scania R520 in standard trim

Vehicle Test date Manipulation Method and tools used	Scania R520 (EURO VI) 14-01-21 No manipulation Both Wabco-Würth and Bosch KTS Truck tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	No MIL	
Note SCR warning lamp	No warnings	
Note urea level on dashboard	37%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	NOx/SCR system ready PM Filter ready	
Check PID's	NOx 3149 / 3204 ppm on cold engine Back pressure 0.006 bar (live) SCR temperature 102°C (live) Urea level 37%	
Read DTC's	AdBlue/DEF heating open circuit	
Step 3: Move to diagnostics	Observations	
Run Authority scan	1 fault on AdBlue, 2 faults on Engine control	
Note presence of SCR system	AdBlue system present	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Test OK (urea pressure 1.3 bar)	
SCR and EGR function test	EGR test OK SCR test OK NOx 452 / 24 ppm Urea flow 19 g/min	
Note sound of urea pump	-	
Conclusion	Vehicle OK	

6.1.5. Scania R520 with software manipulation

Vehicle Test date Manipulation Method and tools used	Scania R520 (EURO VI) 23-01-21 Software: SCR system deactivated by re-flashing ECU. Physical: SCR controller and pump power supply disconnected. Both Wabco-Würth and Bosch KTS Truck tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	No MIL	
Note SCR warning lamp	No warnings	
Note urea level on dashboard	37%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	No readiness detected from SCR sensor, while engine is running	
Check PID's	No live data from SCR sensor, while engine is running	
Read DTC's	-	
Step 3: Move to diagnostics	Observations	
Run Authority scan	-	
Note presence of SCR system	-	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	-	
SCR and EGR function test	-	
Note sound of urea pump	-	
Conclusion	Software manipulation detected by missing live data (data stream) from NOx-sensor.	

6.1.6. Volvo FH500 in standard trim

Vehicle	Volvo FH500 (EURO VI)	
Test date	02-02-21	
Manipulation	No manipulation	
Method and tools used	Both Wabco-Würth and Bosch KTS Truck tool used	

Step 1: Ignition key on/off	Observations
Note state of MIL	No MIL
Note SCR warning lamp	No warnings
Note urea level on dashboard	25%
Step 2: Connect Scan tool	Observations
Check readiness monitors	Status of monitored components OK
Check PID's	Back pressure 0 kPa Urea pressure 1.76 kPa
Read DTC's	Number of stored trouble codes = 0
Step 3: Move to diagnostics	Observations
Run Authority scan	Scan OK
Note presence of SCR system	Exhaust aftertreatment control unit present
Run NOx sensor test	-
Step 4: Self-test (Super PIN)	Observations
Urea pump and leakage test	-
SCR and EGR function test	EGR flow 0.16 kg/min
Note sound of urea pump	-
Conclusion	Vehicle OK

6.1.7. Volvo FH500 with bad wiring

Vehicle	Volvo FH500 (EURO VI)
Test date	02-02-21
Manipulation	Plug pulled to SCR unit
Method and tools used	Both Wabco-Würth and Bosch KTS Truck tool used

Step 1: Ignition key on/off	Observations
Note state of MIL	-
Note SCR warning lamp	-
Note urea level on dashboard	-
Step 2: Connect Scan tool	**Observations**
Check readiness monitors	-
Check PID's	-
Read DTC's	10 active DTC's in exhaust after treatment
Step 3: Move to diagnostics	**Observations**
Run Authority scan	Number of faults in ACM = 2
Note presence of SCR system	Lost communication with EECU Lost communication with Emission Monitoring System
Run NOx sensor test	-
Step 4: Self-test (Super PIN)	**Observations**
Urea pump and leakage test	-
SCR and EGR function test	-
Note sound of urea pump	-
Conclusion	Vehicle rejected

6.1.8. Volvo FE280 in standard trim

Vehicle Test date Manipulation Method and tools used	Volvo FE280 (EURO V) 03-02-21 No manipulation Wabco-Würth tool used
Step 1: Ignition key on/off	Observations
Note state of MIL	Lamp test OK then MIL off at engine start
Note SCR warning lamp	No warning
Note urea level on dashboard	-
Step 2: Connect Scan tool	Observations
Check readiness monitors	Status of monitored components OK Catalyst monitors not ready
Check PID’s	Urea pressure 0 kPa
Read DTC’s	Number of stored DTC’s = 0 6 inactive DTC’s 1 active DTC (AdBlue filter heater)
Step 3: Move to diagnostics	Observations
Run Authority scan	Failure on SCR (urea heater)
Note presence of SCR system	-
Run NOx sensor test	-
Step 4: Self-test (Super PIN)	Observations
Urea pump and leakage test	-
SCR and EGR function test	-
Note sound of urea pump	-
Conclusion	Vehicle OK. Urea heater in need of maintenance

6.1.9. DAF XE 440 in standard trim

Vehicle	DAF XE 440 (EURO VI)
Test date	08-02-21
Manipulation	No manipulation
Method and tools used	Wabco-Würth tool used
Step 1: Ignition key on/off	Observations
Note state of MIL	Lamp test OK then MIL off at engine start
Note SCR warning lamp	No warning
Note urea level on dashboard	37%
Step 2: Connect Scan tool	
Check readiness monitors	-
Check PID’s	Urea pressure 8.9 bar Urea level 37.1% Urea pressure 8.8 bar NOx 244/231 ppm DPF Back pressure 7 mbar AdBlue dosing 588.6 g/h
Read DTC’s	No trouble codes stored in system
Step 3: Move to diagnostics	
Run Authority scan	-
Note presence of SCR system	-
Run NOx sensor test	-
Step 4: Self-test (Super PIN)	
Urea pump and leakage test	-
SCR and EGR function test	-
Note sound of urea pump	-
Conclusion	-

6.1.10. DAF XE 440 with software manipulation

Vehicle	DAF XE 440 (EURO VI)	
Test date	08-02-21	
Manipulation	Software: SCR system deactivated by re-flashing ECU through CAN-bus protocol (OBD). Physical: SCR pump power supply disconnected.	
Method and tools used	Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No warning for low urea level	
Note urea level on dashboard	Urea tank level shows 0%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	-	
Check PID’s	-	
Read DTC’s	-	
Step 3: Move to diagnostics	Observations	
Run Authority scan	-	
Note presence of SCR system	-	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	-	
SCR and EGR function test	SCR System check shows no line pressure (“Priming and emptying the AdBlue system”).	
Note sound of urea pump	No sound of pump when turning off engine at operating temperature	
Conclusion	Vehicle rejected due to signs of manipulation	

6.1.11. Iveco Eurocargo 160-280 with software manipulation

Vehicle Test date Manipulation Method and tools used	Iveco Eurocargo 160-280 (EURO VI) 18-02-21 Software: SCR system deactivated by re-flashing ECU through CAN-bus protocol (OBD). Both Bosch KTS and Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No control light for low urea level	
Note urea level on dashboard	Urea tank level shows 0%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	-	
Check PID's	AdBlue pressure 8990 mbar (in standard trim only)	
Read DTC's	Several intermittent faults	
Step 3: Move to diagnostics	Observations	
Run Authority scan	-	
Note presence of SCR system	-	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Operation failed	
SCR and EGR function test	SCR System check shows no line pressure.	
Note sound of urea pump	No sound of urea pump when turning off engine at operating temperature	
Conclusion	Vehicle rejected due to signs of manipulation	

6.1.12. Mercedes Actros IV 1845 in standard trim

Vehicle Test date Manipulation Method and tools used	Mercedes Actros IV 1845 (EURO VI) 11-03-21 Not possible without physical means Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	MIL goes on, off, then blinks MIL lights up for 10 seconds at engine ON	
Note SCR warning lamp	No urea lamp in dashboard Display reads "Service immediately"	
Note urea level on dashboard	Urea gauge shows 30%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	All system read "Ready" Number of stored DTC's = 0	
Check PID's	Reagent level 33% Backpressure rises to 0,46 kPa with throttle actuation	
Read DTC's	1 DTC: Adblue resistor heater short	
Step 3: Move to diagnostics	Observations	
Run Authority scan	-	
Note presence of SCR system	-	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Urea pressure reads 7,9 bar Metering amount test OK	
SCR and EGR function test	SCR test OK	
Note sound of urea pump	Urea pump comes on (audible) then clicks	
Conclusion	Service warnings and one pending DTC is not enough to incriminate the vehicle. A service is recommended, however	

6.1.13. Mercedes Arcos 2651 in standard trim

Vehicle Test date Manipulation Method and tools used	Mercedes Arcos 2651 (EURO VI) 11-03-21 Not possible without physical means Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	MIL blinks slowly at Key ON. MIL goes off at engine ON.	
Note SCR warning lamp	Green urea light comes ON OBD tester light comes ON	
Note urea level on dashboard	1500 km / 30%.	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	Some systems not available Monitored systems read "Yes" Some systems not ready	
Check PID's	Reagent Tank Level 31%	
Read DTC's	Several DTC's overall 1 DTC on ACM "Temperature low" Stored DTC's = 0	
Step 3: Move to diagnostics	Observations	
Run Authority scan	Several DTC's overall 1 DTC on ACM Some tests not carried out Urea pressure reads 10 bar MIL cannot be activated PID $3D DPF Delta Pressure rises with engine RPM, reads 500 Pa = 5 mbar PID $3D NOx sensor reads 1650 ppm on cold engine	
Note presence of SCR system	SCR-system present	
Run NOx sensor test		
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Urea pressure reads 9,8 bar NOx sensors are warming up automatically	
SCR and EGR function test		
Note sound of urea pump		
Conclusion	A high number of DTC's does not incriminate the vehicle. One emission related DTC is deemed harmless as it is due to temperature.	

6.1.14. Scania R360 in standard trim

Vehicle Test date Manipulation Method and tools used	Scania R360 (EURO V) without DPF/SCR 11-03-21 No manipulation Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	No MIL at key ON	
Note SCR warning lamp	Not installed	
Note urea level on dashboard	Not installed	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	Readiness OK, no monitors Data lists, EGR ready OK	
Check PID's	EGR % = 8,7	
Read DTC's	DTC = 0	
Step 3: Move to diagnostics	Observations	
Run Authority scan	2 DTC's on engine management (not emission critical)	
Note presence of SCR system	AdBlue unit shown in systems but not installed on vehicle	
Run NOx sensor test		
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	No test available	
SCR and EGR function test	No test available	
Note sound of urea pump	Not installed	
Conclusion	While the OBD systems differs somewhat from other trucks it does not incriminate the vehicle. The manufacturer should be contacted to determine if the absent MIL is normal.	

6.1.15. Mercedes Actros 3 2548 in standard trim

Vehicle Test date Manipulation Method and tools used	Mercedes Actros 3 2548 (Euro V) 03-02-21 The NOx sensor plug on this vehicle was pulled to simulate a physical fault or manipulation. Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	Urea warning light comes on	
Note urea level on dashboard	Urea 15%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	Status, readiness OK	
Check PID's	No urea tank level No DPF back pressure	
Read DTC's	2 DTC's confirmed	
Step 3: Move to diagnostics	Observations	
Run Authority scan	Urea tank level 31% Urea pressure 4,9 bar (live) NOx ppm invalid (cold engine) NOx PID invalid (warm engine)	
Note presence of SCR system	-	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	AdBlue pump test 1,6 bar Pump is very silent! SCR activation test shows "active" NOx sensor self-diagnose shows "OK"	
SCR and EGR function test	-	
Note sound of urea pump	-	
Conclusion	Vehicle is rejected due to the urea warning light, inconsistent pressure and missing NOx PID on warm engine	

6.1.16. Mercedes Actros IV in standard trim

Vehicle	Mercedes Actros IV (Euro VI)	
Test date	03-02-21	
Manipulation	No manipulation	
Method and tools used	Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No warning	
Note urea level on dashboard	Urea 70%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	Readiness OK	
Check PID's	Urea 65.5% Urea pressure 10.034 bar Back pressure 15 mbar (live) Upstream NOx 220 ppm	
Read DTC's	DTC's = 0	
Step 3: Move to diagnostics	Observations	
Run Authority scan	Aftertreatment OK	
Note presence of SCR system	ACM (Exhaust aftertreatment system) OK Metering urea flow rate 5 kg/h only when vehicle is moving	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	-	
SCR and EGR function test	Urea pressure 10.03 bar	
Note sound of urea pump	-	
Conclusion	Vehicle OK	

6.1.17. Actros 1845 with possible faults

Vehicle Test date Manipulation Method and tools used	Mercedes Actros 1845 (Euro VI) 03-02-21 No manipulation Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No warning	
Note urea level on dashboard	Urea level 65%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	-	
Check PID's	-	
Read DTC's	-	
Step 3: Move to diagnostics	Observations	
Run Authority scan	ACM DTC Stored and MIL !! NOx out shows 0ppm NOx in shows 0°C	
Note presence of SCR system	-	
Run NOx sensor test	NOx sensor test OK	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Leak test OK Urea pressure 4294972 bar !!!	
SCR and EGR function test	-	
Note sound of urea pump	-	
Conclusion	The vehicle is most likely manipulated or malfunctioning.	

6.1.18. Iveco S-Way 570 brand new

Vehicle Test date Manipulation Method and tools used	Iveco S-Way 570 (Euro VI-d) 26-03-21 Not possible to manipulate (too new) Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK, then blinking, OFF on engine start	
Note SCR warning lamp	Lamp is integrated in multifunction display	
Note urea level on dashboard	20%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	NOx/SCR aftertreatment not ready PM Filter ready NMHC not ready Exhaust gas sensor ready	
Check PID's	Reactant tank level 22.4% Average demanded regen consumption 0.37 l/h (live) Back pressure 0.3-0.5 kPa (live) NOx warning system activation status 'no' NOx concentration 65535 ppm (cold) NOx ppm 130-300 / 65535 (warm) Distance since DTC clear 655km	
Read DTC's	Number of stored trouble codes = 0	
Step 3: Move to diagnostics	Observations	
Run Authority scan	Not possible, vehicle too new	
Note presence of SCR system	Not possible, vehicle too new	
Run NOx sensor test	Not possible, vehicle too new	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Not possible, vehicle too new	
SCR and EGR function test	Not possible, vehicle too new	
Note sound of urea pump	Pump sounds for 60 seconds	
Conclusion	Vehicle OK	

6.1.19. Scania G410 in standard trim

Vehicle Test date Manipulation Method and tools used	Scania G410 DC13 (Euro VI) 25-03-21 No manipulation Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No lamp visible in dashboard	
Note urea level on dashboard	47%	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	NOx/SCR aftertreatment ready NMHC catalyst ready Exhaust gas sensor not available PM Filter ready Emission system readiness 'NO'	
Check PID's	Urea 47% Urea 9 bar Upstream NOx 226 ppm (live) DPF 0,01 bar (live) DOC/DPF temp (live)	
Read DTC's	Number of stored trouble codes = 0	
Step 3: Move to diagnostics	Observations	
Run Quick/Authority scan	AdBlue system, Number of Faults 2 (inactive) Systems->Antipollution (AdBlue) Data lists->All->Show->PRINT (OK)	
Note presence of SCR system	AdBlue system OK	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Reductant pressure sensor check - pump sounds, 9.8 bar.	
SCR and EGR function test	Function test SCR 335 C = Active! NOx ppm 585/53, Flow 16 g/min CR 89% Function test EGR – operation failed	
Note sound of urea pump	Pump sounds (video clip available)	
Conclusion	Vehicle OK	

6.1.20. Scania G410 with software manipulation

Vehicle Test date Manipulation Method and tools used	Scania G410 (Euro VI) 26-03-21 ECU flashed, EGR+AdBlue off Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No lamp visible in dashboard	
Note urea level on dashboard	62%. The gauge reads a fake value which would not rise any concern unless the true value was known. In the case of this study, however, we knew the true value and thus knew the reading was fake. As consequence, we have marked it yellow due to a 'suspicious' reading. For an unsuspecting inspector it would not be noticeable without topping up the urea tank or using other physical inspection means to reveal the true level.	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	NOx/SCR aftertreatment NOT ready NMHC catalyst NOT monitored. Exhaust gas sensor not available PM Filter NOT ready Emission system readiness not on list EGR/VVT system ready (NO, not available)	
Check PID's	Urea level 61% (fake). Same concerns as in Step 1. Urea pressure 9 bar (not live) Upstream NOx 250 ppm (live) DPF 0.49 kPa (live) DOC/DPF temperatures live Requested quantity of reductant = 0 Pump RPM 1000 (live)	
Read DTC's	P203F Reductant kevel ow (true, refilling was just done)	
Step 3: Move to diagnostics	Observations	
Run Authority scan	AdBlue system, number of faults 1 (inactive) Systems->Antipollution (AdBlue) Data lists->All->Show->PRINT (empty print)	
Note presence of SCR system	Present	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	Reductant pressure sensor check - pump sounds, 9.6 bar	
SCR and EGR function test	Function test EGR – operation failed Function test SCR - Temperature is live - NOx 0 ppm Sensor NOT OK.	
Note sound of urea pump	Pump sounds	
Conclusion	Vehicle rejected.	

6.1.21. Scania G410 with emulator ON

Vehicle Test date Manipulation Method and tools used	Scania G410 (Euro VI) 26-03-21 Sercon Emulator installed Emulator can be switched on/off from the cockpit. Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No lamp visible in dashboard	
Note urea level on dashboard	68% (fake). Same concerns as in 6.1.20	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	NOx/SCR aftertreatment NOT ready NMHC catalyst NOT ready Exhaust gas sensor not available PM Filter NOT ready Emission system readiness not on list EGR/VVT system ready	
Check PID's	Urea level not shown Urea pressure not shown Upstream NOx 0 ppm (not live) DPF 0,98 kPa (live) DPF temperatures (live)	
Read DTC's	Number of stored trouble codes = 0	
Step 3: Move to diagnostics	Observations	
Run Authority scan	AdBlue system, not present on list Systems->Antipollution (AdBlue) The vehicle is not responding to the diagnostic enquire made Data lists->Not available (AdBLue system)	
Note presence of SCR system	No communication with EEC / EEC not responding	
Run NOx sensor test	-	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	-	
SCR and EGR function test	Function test EGR – operation failed Function test SCR Cat temperature fixed at 326 °C (fake value) Test failed to reach threshold temperature	
Note sound of urea pump	No sound	
Conclusion	Vehicle rejected	

6.1.22. Scania G410 with emulator OFF

Vehicle Test date Manipulation Method and tools used	Scania G410 (Euro VI) 26-03-21 Sercon Emulator installed Emulator can be switched on/off from the cockpit. Wabco-Würth tool used	
Step 1: Ignition key on/off	Observations	
Note state of MIL	Lamp test OK then MIL off at engine start	
Note SCR warning lamp	No lamp visible in dashboard	
Note urea level on dashboard	46% (true)	
Step 2: Connect Scan tool	Observations	
Check readiness monitors	NOx/SCR aftertreatment NOT ready NMHC catalyst ready Exhaust gas sensor not available PM Filter ready Emission system readiness not on list EGR/VVT system ready	
Check PID's	Screenshot saved (this was done from Step 3) Urea level 46% Urea pressure 8.9-9.2 (live) NOx 3247/3287 ppm DPF 0.009 bar (live) DPF temperature 157°C (live)	
Read DTC's	Number of stored trouble codes = 0	
Step 3: Move to diagnostics	Observations	
Run Authority scan	G-series 2007-2018 (VIN auto detected) AdBlue system OK Systems->Antipollution (AdBlue) Data lists-> All Show OK (no print)	
Note presence of SCR system	AdBlue system OK	
Run NOx sensor test	No test without Super PIN	
Step 4: Self-test (Super PIN)	Observations	
Urea pump and leakage test	-	
SCR and EGR function test	Function test EGR – operation failed Function test SCR, temperature shows correctly NOx=579/128ppm (live) Reduction 100%	
Note sound of urea pump	Sound OK	
Conclusion	Inconclusive	

6.2. Application at Periodical Technical Inspection (PTI).

The method developed in this report may be proposed for future PTI. Step 1 should be part of a PTI as it is quick and requires no tools. Step 2 is also recommendable as it requires only basic OBD tools and can be done in a matter of minutes. Step 3 requires a more advanced OBD tool but otherwise it does not differ that much from Step 2 because all functions are available on an advanced tool. The main issue is that the engine must be warmed up for the NOx sensors to activate. Step 4 is the most powerful inspection tool, but also the most time consuming. It could add significantly to the cost of PTI if implemented.

Step 2-4 also requires significant skills from the operator. The PTI official is therefore an important part of the method. With enough experience and training the PTI official will be able to distinguish important OBD data from less important ones. It would be tempting to simply count the number of red and yellow flags, but the inspections done in section 6.1 do not provide sufficient confidence in such approach. The decision on whether to reject a vehicle at future PTI's should be further elaborated.

7. Conclusion

The combination of an OBD diagnostics tool with a skilled operator can be used effectively to detect faulty or manipulated emissions system on heavy trucks.

A step-by-step method has been provided in this report. The method clearly detects mechanical and electrical faults. Even though the method also can strongly indicate illegal manipulation, the final proof should include physical signs, such as missing/disconnected sensors and plugs, or be verified in a specialized workshop.

The relatively clear signs of manipulated or malfunctioning systems are:

- MIL stays on while engine is running
- Urea warning light stays on
- Urea gauge reads 0%
- SCR System check shows no line pressure.
- No live data/readiness detected from SCR sensor, while engine is running.
- Urea system or complete ACM system missing from EOBD
- Self-test on SCR system failed
- Urea leak test failed
- NOx PID shows a fixed value not moving with warm engine
- Back pressure PID not moving with throttle actuation
- No change in urea pump pressure at engine shutdown

Other tell-tell signs:

- Urea level PID not matching dashboard reading
- MIL blinking

Signs which should be neglected:

- Pending DTC's
- Readiness monitors that read "incomplete."

- Missing self-test functions
- Silent running urea pumps if pressure reads OK

8. Nomenclature

ACM (Active Control Module) - a submenu in Wabco-Würth tester
AdBlue – a commercial name for urea
DEF (Diesel Exhaust Fluid) – a name used for urea, AdBlue, reagent, reductant
de-NO_X – general term for systems for removal of NO_X
DLC (Data Link Connector) – a name for the OBD-plug
DOC
DPF (Diesel particulate Filter) – a system that reduces soot and other particulate emissions
ECU (Engine Control Unit) – an on-board computer that controls the engine
EEC (Exhaust Emission Control) - a submenu in Wabco-Würth tester
EGR (Exhaust Gas Recirculation) – a system used to reduce NO_X emissions
EGS (Exhaust Gas Sensor) – a sensor in the exhaust system
Emission Reduction – common term for filters, catalysts etc. on vehicles
IUPRs (In-Use Performance Ratios) – internal self-check values in the OBD
MIL (Malfunction Indicator Lamp) – a generic dash board light that turns on in case of emission-critical conditions detected by the OBD
NMHC Catalyst (Non-Methane Hydro Carbon) – synonym for ammonia slip catalyst
NOx (Nitrogen Oxides) – harmful exhaust gases that cause smog, acidification, and respiratory problems
OBD (On-Board Diagnostics) – a system that detects fault on vehicle systems and allows communication with vehicle control units
OEM (Original Equipment Manufacturer) – Vehicle manufacturers and their direct sub-suppliers
PM Filter (Particulate Matter Filter) – synonym for DPF
PTI (Periodical Technical Inspection) – Mandatory vehicle inspections also known as 'MOT'
Reagent – a common name used for urea, AdBlue, reductant or DEF
RPM (Revolutions Per Minute) – a measure of engine speed
SCR (Selective Catalytic Reduction) – a type of catalyst for NO_X reduction
Super PIN – a speciel activitation code needed for some vehicle self-test functions on Wabco-Würth
Urea – a reagent used in SCR catalysts
WHTC (World Harmonized Test Cycle) – a type approval test cycle for truck engines

9. Literature list

1. Frandsen, Sten: "Investigation of NOx manipulation in heavy-duty vehicles - Screening of emulator devices and potential control methods to detect NOx manipulation", March 2018, TS2060107-007877
2. International Counsil for Clean Transportation: "GLOBAL OVERVIEW OF ON-BOARD DIAGNOSTIC (OBD) SYSTEMS FOR HEAVY-DUTY VEHICLES"

3. Vehicle Emissions On-Board Diagnostics (OBD) | State and Local Transportation Resources | US EPA
4. Transportpolicy.net
5. Tables 1 to 4 in Appendix 5 of Annex 9B to R49
6. UNECE Global Technical Regulation no. 5 (WWH-OBD) Section 4.5
7. SAE J1979/ISO 15031-5 “Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 5: Emissions-related diagnostic services”

TEKNOLOGISK
INSTITUT