modales
Adapting driver behaviour for lower emissions

Project Results

OBD, inspections and retrofits

The MODALES project built a user-centric approach addressing the challenges of emissions from different sources in road vehicles.

It researched, developed and tested a number of innovative and complementary solutions encompassing the Driver, On-Board Diagnostics (OBD), Periodic Inspections and Retrofits.

This results factsheet covers the three areas of On-Board Diagnostics (OBD), Periodic Technical Inspections (PTI) and Retrofits for diesel vehicles. A separate factsheet, 'Driver' summarises results on how changing driving behaviour can reduce emissions.

Visit the MODALES website to find out more about the project and its results: modales-project.eu

On-Board Diagnostics – OBD

Work in this domain centred on logging requirements for the project and recommendations for a broader use of OBD. This included investigating the performance of European OBD (EOBD) to detect malfunctions and deteriorated performance of the Engine Aftertreatment System (EATS).

An improvement in EOBD performance would result in higher rate of detection in poorly maintained and/or tampered vehicles with elevated exhaust emissions. The literature review carried out by MODALES revealed critical flaws in present EOBD. It was found that the system is not robust enough when it comes to tampering. Crucial defects in the current system are that Diagnostic Trouble Codes (DTCs) can be easily cleared using readily available and low-cost communication tools, avoiding entrapment in a Periodic Technical Inspection (PTI). Furthermore, new software can be loaded into the Engine Control Unit (ECU) to increase engine power output and to disable EATS functionalities to alter the system in such a way that it avoids triggering DTCs.

Regarding recommendations for a broader use of OBD:

- MODALES foresees the use of data that is accessible via OBD plus additional information from third party devices to identify driver behaviour, which might have an impact on emissions later, as well as on wear and tyre throughout the lifespan.
- MODALES proposed several recommendations from a legal point of view, based on a MODALES study on the legal situation regarding tampering in European countries.
- Recommendations have also been made regarding the lack of available services to detect and reduce/eliminate vehicle tampering.

Periodic Technical Inspections – PTI

Work in this area investigated the detection of tampering or malfunctions in vehicles by considering a wide range of technical, behavioural and legal criteria, in order to clarify the current and future capabilities of the EOBD protocol.

The current characteristics of the EOBD protocol were studied in order to suggest improvements. The project has also studied other user behaviours, given by technicians, garages and tuning centres on poor maintenance or tampering, taking into account the real effectiveness of OBD and periodic inspections.

Additionally, an in-depth analysis of the vehicle inspection data was performed with data provided from Turkey, Finland and Spain. By analysing PTI data, one might conclude that a year-on-year increase in random emission checks (leading to a greater number of penalties being issued for violations), has a positive effect on reducing emission failures. Also, overloading of trucks and buses may be one of the reasons for increased failure percentages. More specific controls and higher penalties for overloading would help combat this.

Two options for vehicle modification and/or manipulation were studied: Engine Control Unit (ECU) reprogramming and/or tampering of the vehicle Engine After-Treatment System (EATS). The results acquired from this demonstration suggests that the effect of different ECU remapping and EATS tampering solutions may change the vehicle performance characteristics relatively significantly. The ECU reprogramming versions adapted in this study were found to affect especially the EATS thermal control, increasing the delay of catalyst activation. No effect on particulates was found for ECU reprogramming with the Diesel Particulate Filter (DPF) installed. On contrary, removal of vehicle EATS neglects totally the suppression of any exhaust pollutants, resulting in exhaust emissions which correspond to engine raw emissions.

MODALES has created and demonstrated software for passenger cars, combining EOBD codes that indicate potential tampering violations or improper maintenance.

Besides these aspects, an overview of best practices and recommendations based on legal research was carried out on vehicle tampering. Analysis of the current situation provided evidence of the need to strengthen regulations and monitoring processes.

Recommendations focused specifically on the alignment of the definitions of tampering and penalties. Secondly, it demonstrated the possible actions to be taken in relation to the obligations placed on manufacturers, which may prevent tampering with vehicles. The prohibition on tampering is most often derived from legislation on type approval processes rather than separate legal provisions. The recommendation suggests that Member States might consider applying rules outside the context of the type approval process in order to prohibit a wider scope of tampering conducts. Lastly, gradual sanctions to be applied in the context of periodic roadworthiness tests and technical roadside inspections can give drivers and owners the opportunity to rectify minor defects, while also allowing authorities to prohibit the use of vehicles that pose a greater degree of danger or damage to the environment.

Retrofits

This task focused on retrofits for different types of diesel vehicles to reduce Nitrogen Oxides (NO_X) emissions from the tailpipe (exhaust). The feasibility and potential of retrofit emission controls was addressed, starting from existing systems on the market that are mainly for urban buses. MODALES expanded the practicality of these applications to light-duty trucks and large vans, with the target of reaching real emission level of Euro 6 in Euro 5 vehicles.

This task also analysed different retrofit technologies for light vehicles and the development and testing of a retrofit SCR (Selective Catalytic Reduction) system to a light commercial vehicle.

The main concerns regarding NO_X emissions from new vehicles are cold start where NO_X after-treatments have low efficiency. A variety of technologies are available to decrease cold start emissions. The main theory of these technologies is to increase exhaust temperature or provide an easier way to deliver gaseous ammonia, ensuring greater efficiency of after-treatment systems. Compared with heavy duty vehicles, some after-treatment technologies lack the flexibility to be installed on passenger cars, due to the limited space.

The key after-treatment technologies are listed in the table below, which provides a summary of the retrofit technologies for dropping cold start NO_X emissions, based on published materials. The effectiveness, energy penalty, and complexity are the key performance indicators. When choosing the techniques, balances among effectiveness, energy penalty, and complexity should be made to achieve the best "performance" from the global perspective.

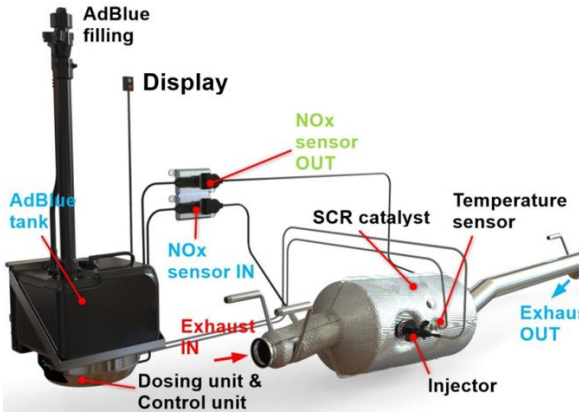
Technology	Response	Energy Penalty	Complexity	Effectiveness
SCR (Selective Catalytic Reduction)	Medium	No/Low	Medium	Medium
LNT (Lean NOx Trap)	Fast	Medium	Medium	Low
ACCT (Ammonia Creation & Conversion Technology)	Fast	Medium/High	Complex	High
ASDS (Ammonia Storage and Delivery System)	Fast	Medium	Complex	High
Thermal Insulation Technology (insulation materials covering SCR system)	Slow	Low	Simple	Low
EHC (Electric Heated Catalyst)	Fast	High	Simple	High
External burner	Fast	High	Simple	High

Summary of the retrofit technologies for reducing cold start NO_X emissions

MODALES studied the feasibility and potential of retrofit emission controls, and experimented with prototype technologies for after-treatment that will retrofit passenger cars and HDVs, targeting a dramatic reduction of NO_X from diesel engines.

Both in-lab and real-world experiments of the retrofit SCR system for light commercial vehicles were carried out on Mercedes-Benz Sprinter Euro 5 models with 4-cylinder 2.2 litre diesel engine. All those vehicles have a Diesel Particulate

Filter (DPF) as original after-treatment system and that was left in place without any modifications.



Operation principle of retrofit SCR system

Test: NOxBUSTER City Light retrofit SCR system installed to vehicle

During early phase testing it was noted that this type of vehicle has very low exhaust gas temperatures at city driving speeds and on the other hand very high exhaust gas temperatures during DPF regeneration.

Emissions and fuel consumption test facility with a single-roller 2WD dynamometer and Mercedes van retrofitted with Proventia NOxBUSTER

Low temperature SCR may not handle temperatures above 500°C and therefore SCR material was changed to withstand up to 600°C during active DPF regeneration. Another challenge was possible hot shut down of engine during DPF regeneration, leading to overheating of urea nozzle. The tests proved that Euro 5 vehicles are optimised for the New European Driving Cycle (NEDC) and does not correlate well with the Worldwide harmonised Light vehicles Test Cycles (WLTC) results in general.

A NO_X reduction of more than 50% over the whole cycle may be achieved depending on test cycle and operating conditions. The reduction (or NO_X conversion efficiency) was much greater when the retrofit system active (sufficient exhaust gas temperatures (EGT) reached), highlighting that retrofit SCR efficiency is highly dependent on the engine out exhaust temperature. Outdoor tests confirmed that the effect of ambient temperature for engine raw NO_X (and CO_2) is significant and ambient temperature affects tail pipe NO_X especially when EGT is lower than the SCR-activation threshold.

The impact of applying diesel SCR retrofit systems on Euro 5 vehicles was a NO_X reduction of 51 - 65% over the whole cycle. When the retrofit system is active, NO_X conversion efficiency was between 59 - 78%. No significant effect on CO_2, CO or HC

found with usage of the Proventia retrofit compared to the original OEM configuration. The efficiency of SCR retrofits is highly dependent on the engine out exhaust temperature and the retrofit system operating window is highly dependent of upstream EGT conditions.

Although the experiment was technically successful, there is no real market for retrofits for vans due to the cost in relation to the value of the vehicle. Retrofits are more a solution for older, larger vehicles (buses and trucks), but already the move away from diesel to electric and other powertrains means that retrofitting is rather a transition technology, nevertheless still relevant where there are older vehicle fleets.

For more information

In-depth results are available in the following reports, available in the Deliverables Library area of the project website (modales-project.eu/deliverables):

- D2.2: Real effectiveness of OBD inspection and maintenance, and retrofits (August 2020, public)
- D2.3: Legal situation of tampering (September 2020, public)
- D4.1: Recommendations for a broader use of OBD (July 2021, public)
- D4.2: Recommendations for anti-tampering and an improved mandatory vehicle inspection (November 2022, public)
- D4.3: Retrofit solutions for road vehicles – public Executive Summary (the main report is confidential)

The parallel project DIAS – Diagnostic Anti-Tampering Systems – also investigated the topic of tampering in greater depth. For more information, see https://dias-project.com

MODALES partners contributing to this set of results

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For further information, visit modales-project.eu or contact info@modales-project.eu