In-service emissions performance of Euro 6/VI vehicles.

A summary of testing using London drive cycles.

MAYOR OF LONDON

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Contents

Background

In Europe, all new vehicles must go through a process of type-approval to ensure that they conform to common standards. Part of this process includes standards for the control of emissions from the vehicle. The Euro 1 standard for light duty vehicles, and heavy duty engines, became mandatory for new vehicles in 1993. Since then a series of progressively tighter Euro emissions standards have required vehicle manufacturers to incorporate new technology to control exhaust emissions from road vehicles.

This paper firstly considers the legislative and technical background to the more recent Euro emissions standards. It then summarises initial results from a programme of TfL testing of the newest (Euro 6) vehicles. These tests show that, under London driving conditions, emissions of the key pollutant, NO_x, are reduced from those of vehicles certified to Euro 4/5 in broad proportion to the reductions expected on examination of the COPERT 4 emissions functions. This is important because the COPERT 4 functions are designed to represent 'real' driving conditions and are widely accepted for emissions modelling purposes.

1. The Legislation

Originally founded in EC directive 70/220/EEC, subsequently replaced by directive 717/2007 for Light Duty vehicles (cars and vans) and 88/77/EEC, later replaced by 05/55/EC for Heavy Duty vehicles (HGVs and buses - HDVs), the Euro standards are a range of successively tightening emissions limits for petrol, gas and diesel engines. Compliance with these emissions limits must be demonstrated as part of the European type-approval process for new vehicles and road vehicle engines. There are also 'durability' requirements to demonstrate continued in-service compliance.

Light Duty vehicles (cars and vans) are subject to whole-vehicle emissions testing, whilst Heavy Duty engines are emissions tested and approved using an engine dynamometer 'bench' test. The limit values are different for each vehicle type, and to indicate which is being discussed, there is a convention that suggests that Euro 6 refers to cars and vans (whole vehicle emission testing), whilst Euro VI refers to Heavy Duty Vehicles (HDVs) and buses (engine only emissions testing).

In each case, the Euro standards set out emissions limits for type approval testing that control four 'legislated' emissions, carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate matter (PM). The use of 'bench' testing for Heavy Duty engines, with emissions measured in grammes per kilowatt-hour (g/KWh) mean that the type approval levels cannot readily be compared with on-highway emissions measurements.

The latest iteration of these standards, Euro VI, has been mandatory for all new heavy duty engines for HDVs and buses since January 2014 , whilst Euro 6 will be mandatory from

September 2015 for cars and light vans, and September 2016 for larger vans up to 3500 kg gross vehicle weight.

Euro standards for motorcycles, mopeds, tricycles and quadricycles (collectively category L vehicles) were instigated later than for larger vehicles. The current standard, being Euro 3, has a NOx limit of 0.15 g/km, which is the same value as a Euro 3 passenger car. Euro 4 for category L vehicles comes into force in 2017.

2. The change in emissions requirements from Euro 5/V to Euro 6/VI

The Euro 6 standard for emissions from light duty cars and vans was defined in UN ECE Regulation 715/2007. The main change is a reduction in the limit for NOx from diesel engines of 55 percent. For diesel cars at Euro 6, the NOx limit reduces from 0.18g/km to 0.08g/km, whilst the other legislated emissions remain unchanged from the previous standard, which was Euro 5b. Euro 5b has been mandatory for new cars since January 2013 and introduced a particle number limit for diesel engines, the first time that a count of particles, rather than a total mass, has been regulated.

Euro 6 petrol engine emissions limits are unchanged from Euro 5, except for the introduction of a particle number limit, in line with that of diesel engines. Passenger cars sold after September 2015 must conform to this limit, although early versions are available sooner. These early examples are approved over the existing New European Drive Cycle (NEDC), but in 2017, a new World Light-duty Test Procedure (WLTP) will be introduced along with a requirement to verify the emissions performance in on-highway driving, known as Real Driving Emissions (RDE). Details of the WLTP and RDE are yet to be finalised by the Commission and interested parties. For larger vans (N1 class 2 and N1 class 3), the diesel engine NOx limit is similarly decreased by 55 percent.

European Regulation UN ECE 595/2009 , introduces the Euro VI standard for heavy duty diesel engines. It reduces the limit for NOx emissions by 77 percent, whilst continuing to set demanding limits for control of particulates and other gases. In addition, the test protocol has been changed to broaden the range of speed/load conditions over which the engine must meet the emissions limits.

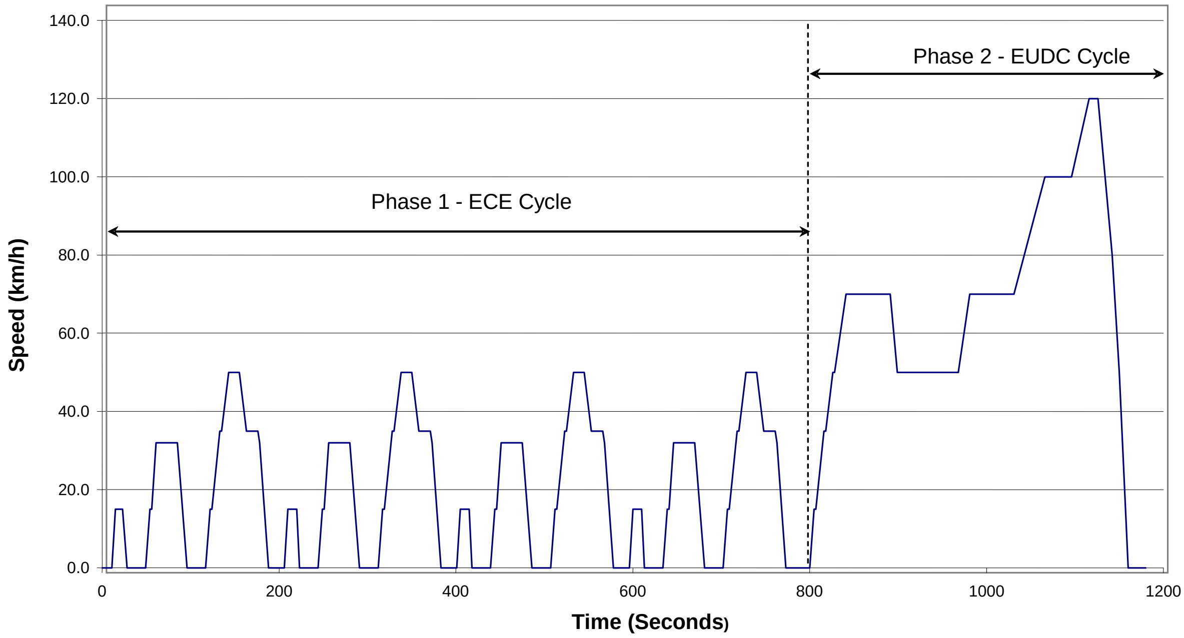
Additionally, for Heavy Duty diesel engines, an ammonia (NH_3) concentration limit of 10 ppm applies to diesel (WHSC + WHTC) and gas (WHTC) engines. This has been introduced to control ammonia slip from Selective Catalytic Reduction systems used to control NOx emissions. A further proposed measure to limit the NO_2 component of NOx emissions (known as primary NO_2) may be defined at a later stage.

Some Euro VI provisions, including an extended on-board diagnosis (OBD) and certain testing requirements are to be phased-in by 2016 for new types and 2017 for all new vehicles, although this is yet to be confirmed by the European Commission.

3. Euro 6 for Light Duty Vehicles

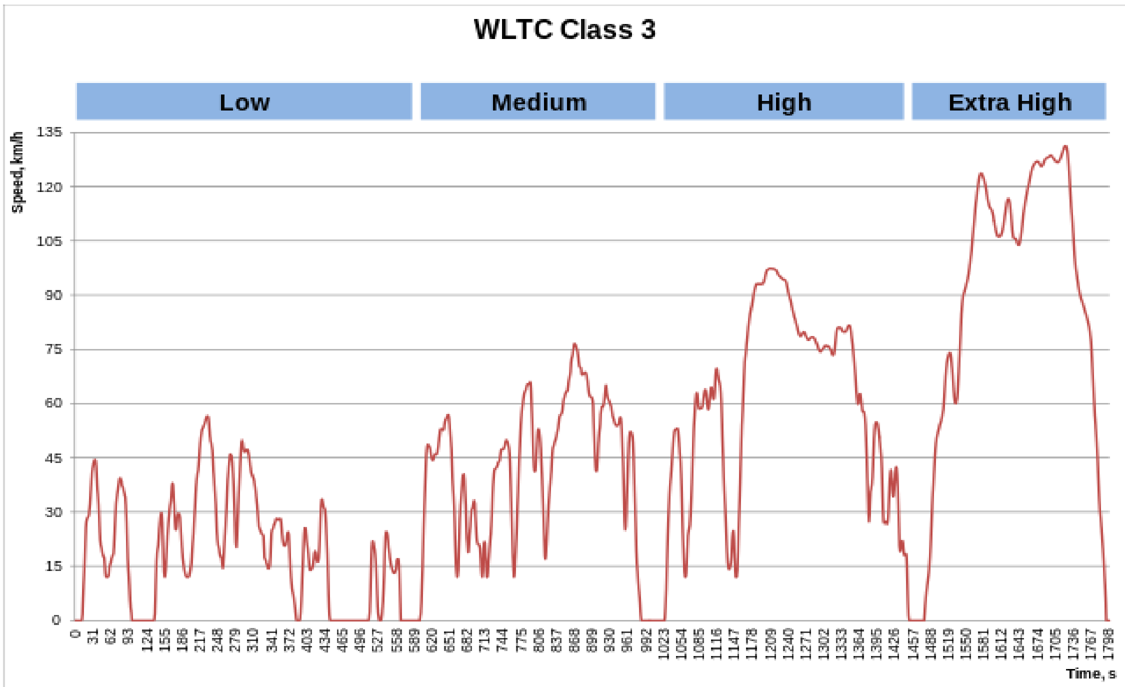
Emissions are currently tested over the New European Drive Cycle (NEDC) chassis dynamometer procedure. The whole vehicle is tested and all emissions are expressed in g/km. Much has been written (including in the popular press) about the extent to which the NEDC fails to represent the real-world driving characteristics of light-duty cars and vans[i]. This has led to, inter alia, a discrepancy between published fuel consumption (and CO_2 emissions) for new cars and their in-service performance. Figure 1 below shows the generic nature of the existing New European Drive Cycle.

Figure 1 New European Drive Cycle (NEDC).



In comparison, the new World-Harmonised Light-duty Test Cycle (WLTC) is shown below. In fact there are three cycles for cars and light vans. The appropriate cycle is chosen according to the power-to-weight ratio of the vehicle. The example below is for class 3, the highest power-to-weight ratio group. The test is 30 percent longer in duration and more transient in nature than the NEDC. The test average speed is 46.5 km/h. (NEDC = 40.65 km/h). This new suite of light duty test cycles should better represent real driving conditions. The new WLTC is expected to be introduced in 2017.

Figure 2 World Light-Duty Test Cycle (WLTC).



3.1 Real Driving Emissions

A further requirement for Euro 6 is for manufacturers to verify the emissions performance of their vehicles in on-highway driving, using portable emissions measurement equipment (PEMS). This process is known as Real Driving Emissions (RDE). It is not possible for a vehicle to meet the Euro 6 type approval emissions limits under all driving conditions that may be encountered, since the duty cycle that the vehicle is operated over may be more demanding than the test cycles. Therefore a ‘conformity factor’ must be agreed by all parties and applied to the on-highway measurements. This would take the form of a multiplication factor. If, for example, the conformity factor were set at 1.5, then the measured on-highway emissions would be allowed to be up to 1.5 times the type approval limit value. At the time of writing, there is no agreement between motor manufacturers and the European Commission on the appropriate level for this conformity factor for Euro 6/VI, nor the date of implementation.

There are certain other detail matters to be agreed regarding RDE. These include the test protocol with regard to altitude and extremes of temperature.

The proposed implementation dates for RDE for light duty vehicles are 2016 for new types and 2017 for existing model ranges, at which time data will be collected to inform the ‘conformity factor’ debate. It is proposed that vehicle types already type approved at Euro 6 will have to demonstrate compliance with the RDE requirements by 2018. However, since these dates are yet to be agreed between motor manufacturers and the European

Commission any further delay will reduce the efficacy of Euro 6 as a number of vehicles may require some recalibration to meet RDE. Table 1 sets out the implementation dates for Euro 6/VI.

Table 1 Euro 6/VI implementation dates.

Standard	Test protocol	New heavy duty engines	All heavy duty engines	new cars & car derived vans	All cars & car derived vans	New larger vans up to 3500kg gvw	All larger vans up to 3500kg gvw
Euro VI	On-highway verification	Jan-13	Jan-14				
Euro 6a	NEDC test cycle			Sep-14	Sep-15	Sep-15	Sep-16
Euro 6 b	WLTP test cycle			2016	2017	2016	2017
Euro 6c	RDE verification			provisionally 2017	provisionally 2018	provisionally 2017	provisionally 2018

3.2 Technical solutions for Light Duty Vehicles

Euro 5 for light duty diesel vehicles required an 80 percent reduction in particulate matter, to 0.005g/km (from Euro 4). This effectively mandated diesel particulate filters on new cars and vans. At the same time NOx emissions limits were reduced by 28 percent. For Euro 6, the particulate limit stays the same, but NOx is further reduced by 65 per cent. Achieving such a reduction will require sophisticated after-treatment, such as advanced exhaust gas recirculation (EGR), Lean NOx Traps (LNT) or, selective catalytic reduction (SCR), to reduce NOx levels. Use of SCR has the advantage that diesel engine manufacturers can use levels of fuel injection timing that will actually increase "'engine-out' NOx, thus improving power and fuel consumption, in the knowledge that the SCR system can be calibrated to reduce the NOx to allowable levels.

For Euro 6 light duty petrol engines, the emission limits are unchanged from those at Euro 5, so current three-way catalyst technology will continue to be the norm. However, some recalibration may be necessary for the forthcoming Worldwide Harmonized Light Vehicles Test Procedure (WLTP).

4. Euro VI for Heavy Duty Vehicles

For Heavy Duty vehicles, the engine is tested in isolation as part of a "bench test". An approved engine may then be used in many different vehicle applications, which may lead to differing fuel consumption and emissions performance. The regulatory emission test cycles have evolved through a number of stages. With the advent of Euro VI, diesel engines are tested over the World Harmonised Stationary Cycle (WHSC) and the World Harmonised

Transient Cycle (WHTC) tests, while positive ignition (gas) engines are tested over the WHTC only. These new cycles are designed to overcome some of the problems experienced with earlier type-approvals whereby an engine passing the type-approval emissions requirements performed very differently in-service, according to the vehicle application.

One of the key changes is the introduction of off-cycle testing (OCE), as introduced by Euro VI regulations. OCE measurements, performed during the type approval testing, follow the NTE (not-to-exceed) limit approach. A control area is defined on the engine fuelling control map (there are two definitions, one for engines with a rated speed < 3000 rpm, and another for engines with a rated speed ≥ 3000 rpm). The control area is divided into a grid. The testing involves random selection of three grid cells and emissions measurement at 5 points per cell. This is a more exacting requirement than was set by the previous ETC and ESC and seeks to avoid the situation seen under previous emissions standards where off-cycle emissions could be higher than anticipated.

Euro VI regulations also introduced in-use testing requirements that involve field measurements using Portable Emissions Measurement Systems (PEMS). The testing is conducted over a mix of urban (0-50 km/h), rural (50-75 km/h) and motorway (> 75 km/h) conditions, with exact percentages of these conditions dependent on the vehicle category. The first of these in-use tests is conducted at the time of type approval emissions testing. Further tests are conducted as part of in-service conformity testing.

Effective from 2005 and 2006, manufacturers must also demonstrate that heavy-duty engines comply with the emission limit values over an extended operating lifespan dependent on the vehicle category. These durability requirements have been extended for Euro VI, to 160,000km/5 years for vans and to 700,000km/7 years for the heaviest HGVs and buses. This requirement, a part of type approval, must demonstrate verification of the correct operation of the emission control devices during the normal life of the vehicle under normal conditions of use ("conformity of in-service vehicles properly maintained and used"). In practice, vehicles are recalled from service to undergo in-service conformity testing.

4.1 Technical Solutions for heavy duty vehicles

For heavy duty diesel engines NOx has been progressively reduced throughout the lifespan of the Euro standards and this continues at Euro VI. All engine manufacturers have utilised either EGR or SCR to comply at Euro V. For Euro VI, many use both systems in combination as the NOx limit is further reduced by 77 per cent on the transient test cycle. Meanwhile particulate mass limits are reduced by a further 60 per cent, which will necessitate the fitment of diesel particulate filters as well.

This level of after-treatment equipment will add to the cost, weight and complexity of the vehicle. For a premium tractor unit, the additional cost is rumoured to be as much as £10,000, whilst weight penalties may be in the region of eighty kilogrammes, when compared with Euro V. Any theoretical fuel consumption penalty is likely to be mitigated by developments in engine calibration that increase the fuel injection advance, improving torque at lower engine speeds and reducing fuel consumption. The sophisticated SCR/EGR combinations would compensate for the resultant engine-out NOx emissions.

5. The NO_x problem

Since the Euro standards first became mandatory for new vehicles in 1993, there have been successive reductions in the permissible limits for four legislated air quality pollutants; carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate matter in the ten micron size range (PM_{10}). The test procedure has also given rise to the official test of carbon dioxide (CO_2) emissions and fuel consumption used for vehicle excise duty and new car advertising. Of these, NO_x and PM_{10} are the emissions of greatest interest because of their effects on human health and EU legislation limiting permissible ambient concentrations. Particulate emissions from diesel exhaust are increasingly well controlled, giving rise to new attention on particulate emissions arising from tyre and brake wear. However, NO_2 ambient concentrations, and therefore NOx emissions, remain a significant challenge.

Despite permissible limits of NOx emissions at type approval reducing significantly, in-service emissions have, in reality, not reduced by anything approaching that amount. For example, in 1993 the permissible limit for NOx emissions from a heavy duty diesel engine was 8 g/KWh. In 2009, Euro V stipulated 2 g/KWh and for Euro VI in 2014, the limit is 0.40 g/KWh. However, emissions measured at the roadside, or in the test laboratory, are frequently of a much greater magnitude.

This is widely attributed to what are known as 'off-cycle emissions'. This effect may be viewed as a failure of the legislation, since the type-approval tests are tightly prescribed and engine manufacturers are obliged to develop specific control strategies to ensure a satisfactory test. However, once type-approved, a heavy duty engine (or a complete car or van in the case of light duty vehicles) may well be operated to different duty cycles to those of the initial approval. Under these circumstances the engine emissions will be quite different to those seen at type-approval, frequently resulting in higher emissions of NO_x. This has led to widespread observations of NO_x emission levels much greater than the type-approval legislation would suggest might be expected. This phenomenon has been widely reported for Euro V heavy duty vehicles.

In drafting the legislation for Euro 6/VI, steps have been taken by the European Commission to correct this problem. For heavy duty diesel engines, where the approval takes the form of an engine-dynamometer 'bench' test, the engine must conform to the required limits over a broader window of speed and load settings. This is followed up by a requirement to verify the emissions performance over a period of on-highway driving with portable emissions analysis equipment fitted to the complete vehicle. These new measures seem, at this early stage, to be effective in controlling 'off-cycle emissions' much more successfully than before. However, they still do not guarantee universal compliance with the standard under all driving conditions.

Authorities across Europe have a responsibility to work towards Limit Values for ambient concentrations of nitrogen dioxide (NO_2). A principal source of NO_2 is the NOx emitted from road vehicle exhausts, particularly from diesels. NO_2 is, for the most part, formed when nitric oxide (NO) present within the exhaust gases oxidises within the atmosphere to form NO_2. Thus, one way to control NO_2 formation is to reduce emissions of NOx and its constituent NO.

However, efforts to reduce emissions of particulate by the use of diesel particulate filters on both light and heavy vehicles, has had the unintended consequence of increasing emissions of NO_2 direct from the vehicle exhaust (known as primary NO_2). This is caused by the action of catalytic coatings within the particulate filter, which are used to cause the filter to regenerate periodically. This trade-off between effective control of particulate matter and formation of an increased NO_2 fraction within total NOx emissions presents an additional challenge.

6. Likely effectiveness of Euro VI

Euro V, in particular, has been heavily criticised for failing to reduce NOx emissions from vehicles in service. This has ultimately led to no significant reduction in roadside concentration levels for nitrogen dioxide (NO_2). This is largely a failing of the regulated test cycles to simulate real world operating characteristics and the prevalence of so called, 'off-cycle emissions'. It seems likely that this situation will be effectively addressed by Euro VI. The key difference, beside further decreased emissions limits, is the revised test procedure for heavy duty vehicles. As described above, instead of emissions measurements at specific speed and load points on the fuel map, this is replaced by a number of zones on the fuel map, within which measurements may be taken at random. This means that the engine must be compliant over a broader range of speed and load conditions.

This has been corroborated in initial testing by Transport for London (TfL), which has indicated a Euro VI bus to have 98 percent lower NO_x emissions than Euro V (down from 9 g/km to 0.2 g/km). This indicates, significantly, that Euro VI engined buses and HGVs will have NO_x emissions better than many Euro 5 diesel passenger cars. This improved effectiveness seems likely to be repeated for diesel vehicles in the light duty classes, dependent on development of the Worldwide Harmonized Light Vehicles Test Procedure discussed above.

7. A programme of testing

In order to better understand the in-service emissions performance of new Euro 6/VI vehicles, TfL has commissioned a programme of laboratory testing, carried out at Millbrook Proving Ground Ltd. The specific area of interest is NO_x emissions and more particularly, as they apply to vehicles circulating on London streets. TfL has a suite of drive cycles developed to enable London urban driving conditions to be replicated in the test laboratory and these are being used to assess the emissions from a range of vehicles chosen to represent the broad range of vehicle types currently in-service. The data collected in this way will allow a direct comparison with tests carried out on similar vehicles of earlier Euro standards[ii] and will inform future emissions modelling work.

Table 2 shows the range of vehicle types included in the TfL test programme. In selecting vehicles for test, the objective was to test a spread of vehicles that represent the vehicle types most commonly seen in London, hence more than one example of certain groups have been tested. At the same time, recognition is given to the practice of 'platform sharing' utilised by vehicle manufacturers, meaning that a vehicle of one brand may be mechanically identical to that of another brand (eg Mazda 6 & Ford Mondeo, VW Passat & Skoda Octavia). Emphasis has been given to diesel engine vehicles since these are the types that present the biggest challenge for NOx emissions. The expectation is that current 3-way catalytic convertors can satisfactorily control gaseous pollutant emissions from petrol engines.

Table 2 Vehicle types included in the TfL Euro 6/VI test programme.

Passenger cars:-
- Compact
- Supermini
- Small family
- Hybrid Saloon – Gasoline
- Hybrid Saloon – Plug-in hybrid
- Family Saloon/MPV
- Prestige Saloon/sports
- SUV/4x4

Goods vehicles:
- Light commercial vehicle – N1 class III – Diesel – 3,500kg GVW
- Heavy Good Vehicle – N2 – 2 axle rigid – Diesel- 7,500kg GVW
- Heavy Goods Vehicle – N3 – 2 axle rigid – Diesel – 18,000kg GVW
- Heavy Goods Vehicle – N3 – 6 axle artic – Diesel – 40,000 kg GVW

For each of the passenger cars, emissions tests were performed using the Transport for London Urban, Suburban and Motorway drive cycles, from a warm start [iii]. These drive cycles representing three differing road types are further divided to represent three differing traffic conditions (Free-flow, AM Peak and Inter-peak). For the goods vehicles, only the Suburban drive cycle was used, but in both un-laden and laden condition. Emissions are sampled over the entirety of the drive cycle and on a second-by-second (1Hz) basis, allowing detailed analysis to be carried out.

There are nine TfL cycles relevant to suburban and urban driving. Table 3 shows the cycle average speeds for each. Urban Inter peak average speed (13.9km/h) is close to the central London average speed of 14.5 km/hr.

Table 3 Cycle average speeds for London drive cycles.

Cycle name	**Cycle average speed**
Urban free flow	26.7
Urban AM peak	15.7
Urban interpeak	13.9
Suburban free flow	49.3
Suburban AM peak	25.3
Suburban interpeak	30.2
Motorway free flow	87.2
Motorway AM peak	47.1
Motorway interpeak	86.1

8. Test results – Passenger car

Table 4 shows cycle average emissions of NO_x, PM and CO_2 measured in grammes/km and compared against the Type Approval limit for each respective light-duty vehicle. The results shown here represent the average emissions measured over all nine TFL drive cycles.

What is clear from the test results is that the particulate mass limit is comfortably met by all vehicles, given the widespread use of exhaust particulate filters. However, emissions of NOx are significantly higher than the type approval limits, as has been seen with previous Euro standards. This may be regarded as an effect of differing drive cycle characteristics on the actual emissions performance of diesel engines, although petrol engine vehicles still beat the emissions limits by a healthy margin owing to three-way catalytic convertor technology.

Table 4 Drive cycle average emissions from light-duty Euro 6 passenger cars.

Market segment	Fuel	NOx		PM		CO_2
		Total approval limit (g/km)	Test average (g/km)	Total approval limit (g/km)	Test average (g/km)	Test average (g/km)
Compact	Petrol	0.06	0.018	0.005	0.001	149.9
Supermini	Diesel	0.08	1.173	0.005	0.001	146.3
Small family 1	Diesel	0.08	0.316	0.005	0.002	165.8
Small family 2	Diesel	0.08	0.445	0.005	0.002	133.1
Small family 3	Diesel	0.08	0.433	0.005	0.001	145.3
Family/MPV 1	Diesel	0.08	0.422	0.005	0.003	148.2
Family/MPV 2	Diesel	0.08	0.096	0.005	0.0003	150.6
Family/MPV 3	Diesel	0.08	0.264	0.005	0.002	142.1
Prestige/sports 1	Petrol	0.06	0.007	0.005	0.002	291.2
Prestige/sports 2	Diesel	0.08	0.287	0.005	0.002	157.1
SUV/4x4	Diesel	0.08	0.361	0.005	0.001	181.6
Hybrid HEV	Petrol	0.06	0.001	0.005	0.000	116.6
Hybrid REEV	Petrol	0.06	0.001	0.005	N/A	102.5

It is important to note that comparison of "real-world" emissions test results with the type approval limits is of limited value. TfL and other authorities carry out emissions and air quality modelling using emissions factors that reflect not just the emissions performance of a given category of vehicle, but also the age of that vehicle, the proportion of the overall vehicle parc made up by that vehicle type, and the annual distances covered by vehicles of that type. The widely recognised COPERT 4 factors, published by the European Environment Agency and the Joint Research Council of the European Commission, are used by Transport for London, so the purpose of this test programme was to assess any variance that may exist between speed/emissions factors derived from the TfL testing and those incorporated within COPERT 4.

The vehicle emissions have also been measured on a second-by-second (1Hz) basis allowing for the emissions to be plotted and compared at a range of speeds. From the passenger cars tested, the emissions of the petrol cars have been averaged for each 1km/h speed increment. This allows the data to be compared with similar data collected previously for Euro 4 cars [ii]. The same process has been carried out for the diesel cars tested. In the case of both the petrol and the diesel car charts, the emissions for three differing types of car have been used. The measured emissions are averaged at each speed increment. The results have been weighted according to the relative size of the market segment for each of the test vehicles. Finally, a polynomial curve has been plotted to allow comparison between Euro 4 and Euro 6 emissions and against the relevant COPERT 4 emissions curve

Figure 3 & figure 4 show the comparison between average emissions at a given speed for Euro 4 versus Euro 6 passenger cars. These indicate that the NOx emissions are substantially reduced at Euro 6. In the case of petrol cars, the measured emissions of NOx are lower than those shown by the COPERT 4 functions. For diesel cars, the real-world NOx emission is consistently higher than the COPERT 4 functions, but are reduced compared to the Euro 4 emissions by a similar margin to that predicted by COPERT 4, indicating that a substantial reduction in NOx emissions can be anticipated. COPERT 4 reflects the fact that vehicles may not achieve the legislated emissions reductions under real-world driving conditions. From an emissions inventories perspective, therefore, it is the **relative** reduction achieved by Euro 6 against previous Euro standards that is of primary importance.

Figure 3 Comparison of London emissions functions with COPERT 4 functions (petrol cars).

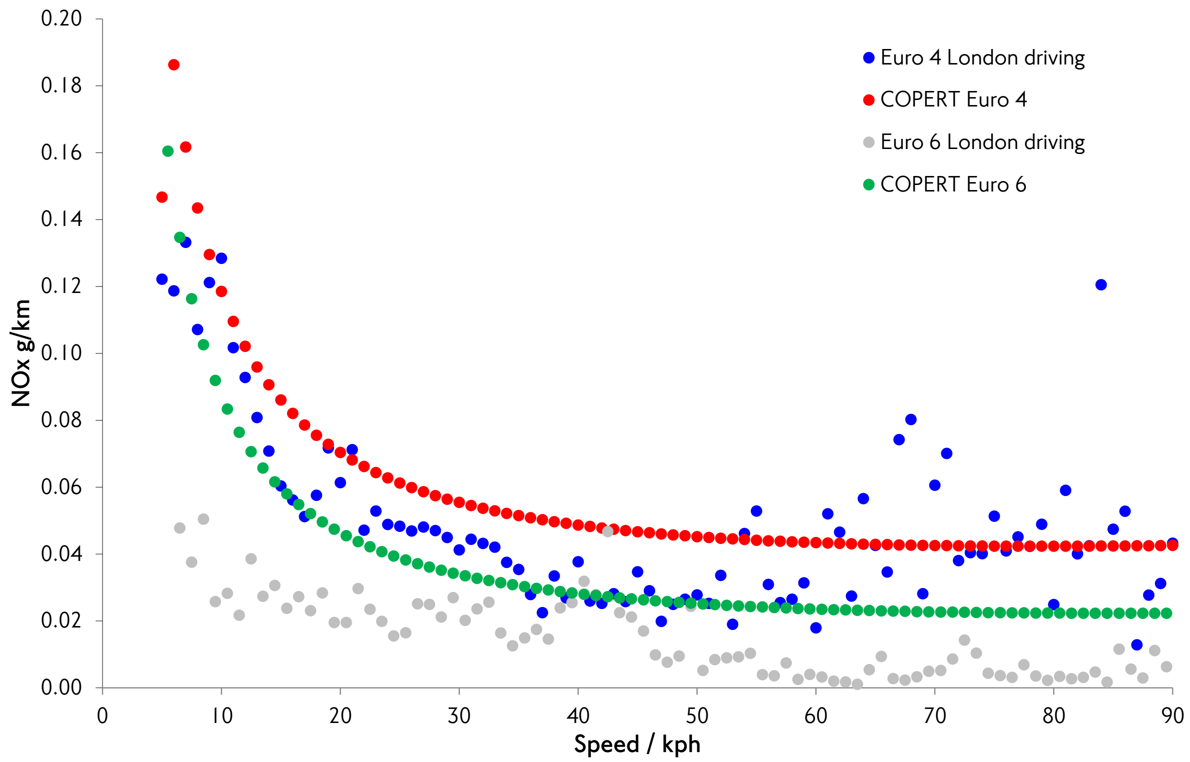
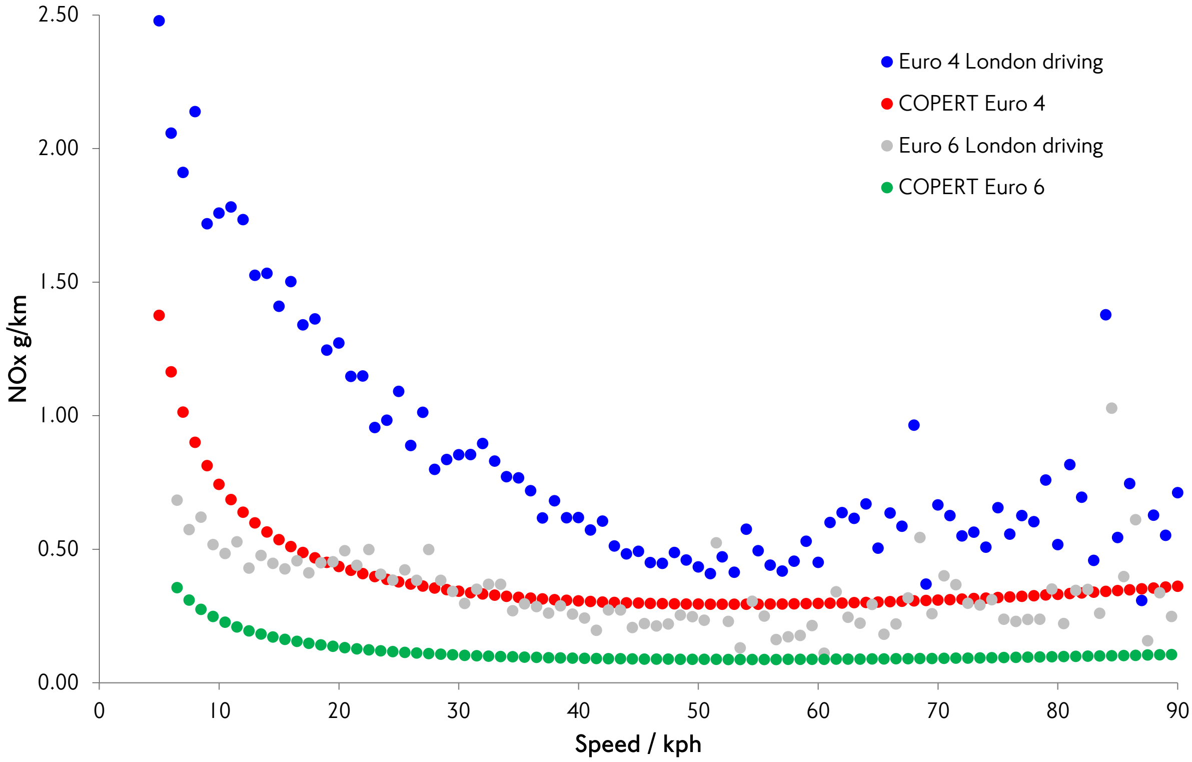


Figure 4 Comparison of London emissions functions with COPERT 4 functions (diesel cars).



9. Test results – Light & heavy goods vehicles

Table 5 shows cycle average emissions of NOx, PM and CO_2 measured in grammes/km for each heavy duty vehicle tested at 0 percent (unladen) and 100 percent (fully laden) condition. The results shown here are the average emissions measured over two of the TfL drive cycles, the Suburban Free-flow and Suburban AM Peak. These two cycles have been determined to be the ones most representative of goods vehicles operation, particularly with regard to rates of acceleration.

Table 5 Drive cycle average emissions from heavy-duty Euro 6 vehicles unladen and fully laden.

Market segment	Fuel	Gross vehicle weight (kg)	NO_x Test average 0% payload (g/km)	NO_x Test average 100% payload (g/km)	PM Test average 0% payload (g/km)	PM Test average 100% payload (g/km)	CO_2 Test average 0% payload (g/km)	CO_2 Test average 100% payload (g/km)
N1 class iii LGV	Diesel	3500	0.494	0.682	0.002	0.001	256.9	290.1
N2 rigid HGV	Diesel	7500	0.71	0.357	0.003	0.003	315.1	470.85
N3 rigid HGV	Diesel	18000	2.714	0.511	0.006	0.007	672.45	921
N3 artic HGV	Diesel	40000	1.407	1.188	0.007	0.007	872.05	1797.45

Whilst levels of PM emission remain consistent regardless of payload, controlled by the diesel particulate filter (DPF), it is interesting to note that the NOx emissions are considerably lower in the fully loaded condition for each vehicle type. This may be attributed to the increased engine exhaust temperatures on the laden vehicle allowing for more effective dosing of the SCR catalyst. In a number of cases, these cycle average emission levels are almost as low as those of diesel passenger cars, indicating the effectiveness of Euro VI at controlling NOx from heavy-duty engines, under the right conditions.

For the HGVs, the emissions have been plotted in 5km/h speed increments allowing comparison with earlier data measured over the same drive cycles for Euro V vehicles. The vehicles chosen represent some of the most common HGV vehicles in use, an 18 tonne two-axle rigid truck and a 40 tonne 6-axle articulated truck. In both cases the results shown are for a fully laden vehicle, demonstrating emissions measured under the conditions that the HGV might be used. As with the cars, the measured emissions have been plotted using a polynomial curve to allow comparison. Figure 5 (18 tone rigid) and Figure 6 (40 tonne artic) illustrate a significant reduction in emissions from Euro V to Euro VI, particularly at the lower speeds seen in urban driving. This gives some indication of the reduction in emissions of NO_x that are being achieved by Euro VI heavy-duty vehicles compared with Euro V and earlier standards. It should be noted that the data plotted here is the result of just one vehicle in each case, albeit examples of some of the most popular models of HGV on UK roads.

Figure 5 Comparison of Euro V versus Euro VI NO_x emissions over a range of road speeds: 18 tonne rigid HGV 100% payload

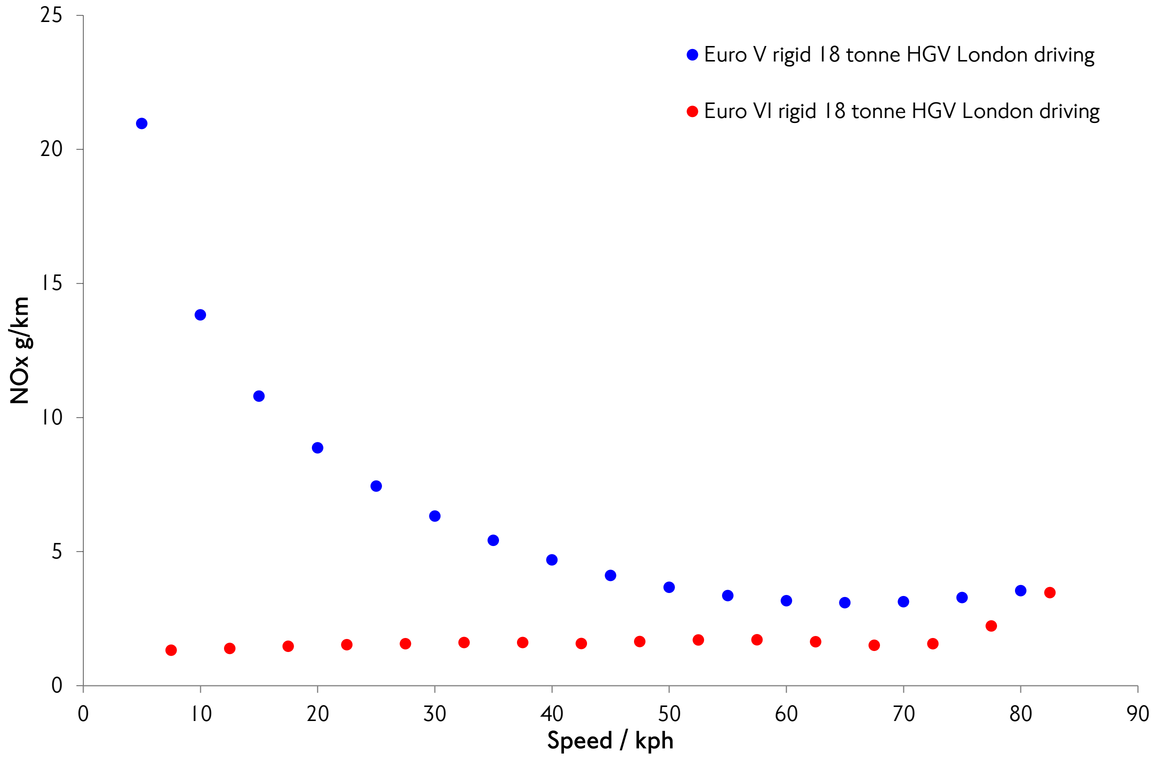
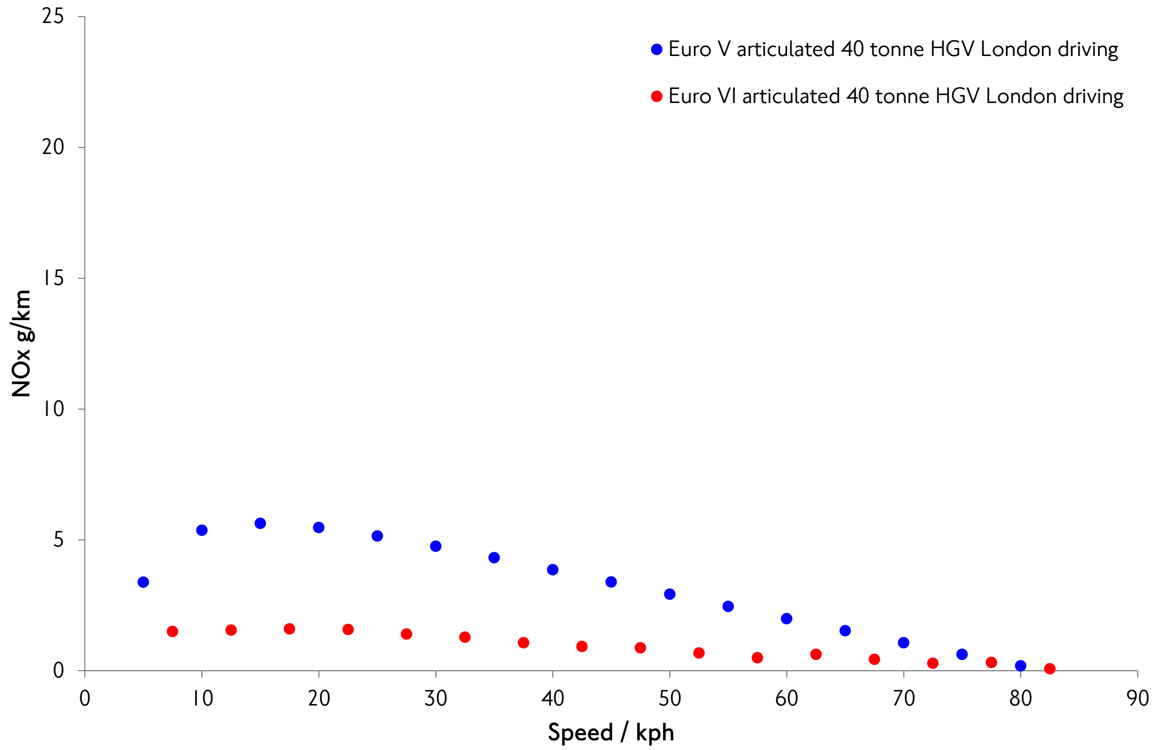


Figure 6 Comparison of Euro V versus Euro VI NOx emissions over a range of road speeds: 40 tonne articulated HGV 100% payload.



10. Conclusions

It can be seen from this analysis of test results that, in urban driving, Euro 6 petrol cars emit very low levels of NOx, consistently less than would be suggested by the COPERT 4 emissions functions. Diesel cars at Euro 6 also show a significant improvement over those at Euro 5, although the plotted emissions are higher than the COPERT 4 functions would suggest. Some models of light-duty diesel vehicles may require re-calibration to satisfy the RDE protocol for emission verification, depending on the conformity factors that are agreed with the European Commission. It is therefore extremely important that the level of conformity factor is set so as to be challenging and that the implementation date is not allowed to slip beyond the proposed 2017/2018. This is necessary to ensure that NOx emission reductions are maximised.

TfL has now tested examples of heavy-duty buses (MLTB cycle) and heavy-duty goods vehicles (TfL Suburban Cycle) at Euro VI. In each case, the results have been impressive, with emissions of NOx significantly reduced from vehicles at Euro V. This is especially true at lower road speeds, which is clearly advantageous for urban and suburban areas.

One area of concern, and for possible further research, is that of primary NO_2 emissions. This is the fraction of total NOx which is constituted of NO_2 at the point that it leaves the vehicle tailpipe. There are suggestions from some quarters that this may be more important when considering human exposure in urban streets than the emissions of NO (which later oxidise in the atmosphere to form secondary NO_2). Some diesel exhaust after-treatment systems increase the fraction of total NOx which is NO_2, despite reducing the total mass emission of NOx. There are discussions at the European Commission, although nothing is definite, about a potential primary NO_2 limit, which may even constitute a future Euro standard (Euro VII ?).

Separately, engine manufacturers and European legislators are turning their attention to reducing carbon emissions from vehicles (CO_2). For passenger cars, plug-in vehicles are starting to achieve wider acceptance, whilst for heavy-duty vehicles, where battery technology is not yet viable, there is still scope for improvement to diesel engines, through advanced control of fuel injection and pressure charging.

References

[i] The Daily Telegraph motoring supplement, Saturday 27th June 2015.

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