London Exhaust Emissions Study

A summary of the drive cycle development, test programme and comparison of test data compared with Type Approval data

MAYOR OF LONDON

TRANSPORT FOR LONDON
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Background

Transport for London has been investigating, as part of our work to develop policies to improve London's air quality and reduce Greenhouse Gas emissions, the CO_2 and air quality emissions from passenger cars and vans in London. Initial work consisted of laboratory testing of vehicles using the Millbrook London Transport Bus (MLTB) Test cycle, since this more closely represented Central London driving conditions than the European type approval drive cycle, known as the New European Drive Cycle (NEDC). The results of this early testing produced some interesting findings and showed that significant scope existed for a more detailed study. This paper is a summary of TfL's work in defining a drive cycle for laboratory testing of passenger cars under London driving conditions. Subsequent papers will describe the selection of suitable test vehicles and analysis of the test results, comparing the emissions performance of passenger cars, light and heavy goods vehicles of Euro 4, 5 and 6 standards.

1. Introduction

EU Directive 70/220/EC (as amended) defines type approval emissions testing for new light duty vehicles throughout Europe. For this purpose a standardised test cycle was introduced during the 1970s and used initially for fuel consumption testing and later, for emissions testing too. It is widely accepted that whilst this European Drive Cycle, later amended and re-titled New European Drive Cycle (NEDC) was consistent and beneficial, it is also generic in nature and does not represent real driving conditions under many circumstances. This causes difficulty when using various emission inventories which are based upon testing using this cycle. For this reason, a limited comparison was conducted by TfL in 2008 to assess some passenger cars using the MLTB test cycle. This work proved sufficiently informative to give rise to this project, whereby a new drive cycle, subsequently divided into a suite of cycles, replicates passenger car driving conditions in London on three different road types (urban, sub-urban and motorway), and three different operating conditions (free-flow, morning peak and mid-day inter-peak). Laboratory tests also record both cold and warm start conditions, which further impact upon the emissions from vehicles. This paper describes the work to define the new drive cycles.

2. Type Approval emissions testing

As described above, the elements of type approval testing concerned with exhaust emissions from passenger cars and light commercial vehicles are conventionally tested over the NEDC test cycle. This cycle is somewhat generic in nature. It includes two distinct phases; the first represents urban driving by four repeats of a stop-start cycle; the second phase represents extra-urban driving and achieves higher speeds. The cycle is driven with the vehicle installed on a rolling road dynamometer. This is a carefully calibrated rolling road, where the emissions are sampled for analysis, with exhaust emissions being captured, sampled and analysed by sophisticated machinery. The NEDC is generally accepted as being somewhat simplistic in nature and as mass emissions from vehicles become smaller and smaller, it is perhaps more obvious that the cycle is not sufficiently 'transient' to show up some emissions effects.

The emissions test duration is 1200 seconds, from a cold start, and the test distance is approximately 11 km. Peak velocity is 120 km/h. The speed trace for the NEDC is shown graphically in figure 1.

Figure 1 New European Drive Cycle (NEDC).

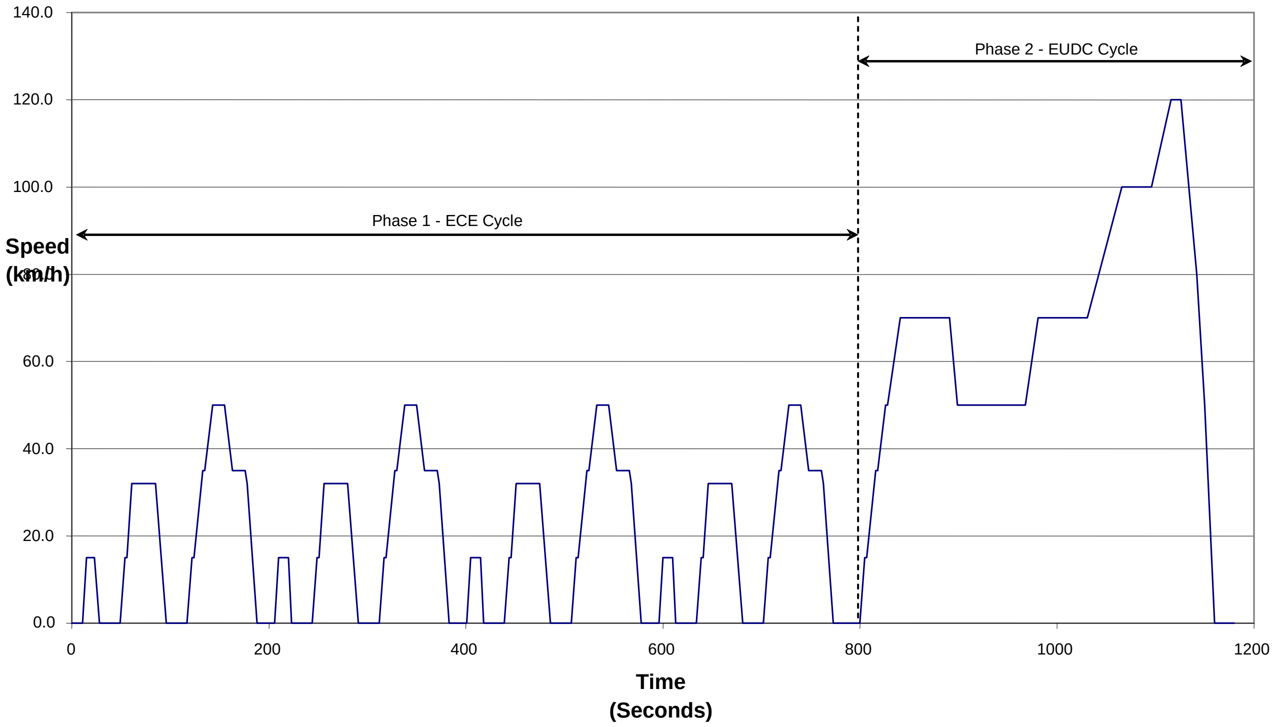


Table 1 NEDC cycle metrics.

Characteristics	Unit	Phase 1 (ECE15)	Phase 2 (EUDC)
Distance	Km	4x1.013 = 4.052	6.955
Duration	Sec	4x195 = 780	400
Average Speed	Km/h	18.7 inc idling	62.6
Maximum Speed	Km/h	50	120

Type approval testing calls for analysis of the vehicle emissions of carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx) and particulate matter measured in both mass and number of particles. Fuel consumption is also measured using the carbon balance method, which produces a figure for carbon dioxide (CO_2) as well. Of the four air quality pollutants analysed, ambient air quality monitoring has determined that NOx and PM_{10} are the most relevant for policy makers, particularly in built-up areas such as London.

The NEDC cycle is also used for "official" fuel consumption declarations used in car advertising. The urban fuel consumption (FC) figure is taken from the first phase, the extra-urban figure from the second phase and the total makes up the overall FC figure.

3. Deriving a new test procedure

In order to derive a test cycle specifically for passenger car driving in London, it was necessary to choose an appropriate route encompassing a representative sample of road and traffic conditions in London, to allow for data to be gathered by driving the route in a car equipped with data logging equipment. In addition, the route choice needed to be selected such that the route could be completed, from a single start point, within the window of varying traffic conditions (eg free-flow, AM peak, inter-peak). The route was chosen by a manual process of studying a detailed map of London to select sections of suitable road. Data logging took place on two different days. To collect the appropriate data, the route was driven three times each day on two separate days, to allow for an "averaging effect" in case of any atypical delays encountered along the way.

In brief, the route commences and finishes at Scratchwood Services on the M1, entering Central London via Brent Cross, Hendon Way and Finchley Road to Marylebone. The route then negotiates part of the West End, Piccadilly and Knightsbridge, heading west via Shepherds Bush and Acton, before turning northwards using a section of the North Circular road between Hanger Lane and Neasden Junction. Some urban roads then connect the route to Junction 1 of the M1 at Staples Corner for the return to Scratchwood Services. Figure 2 below, shows the route.

Figure 2 Map illustrating the route for data logging.

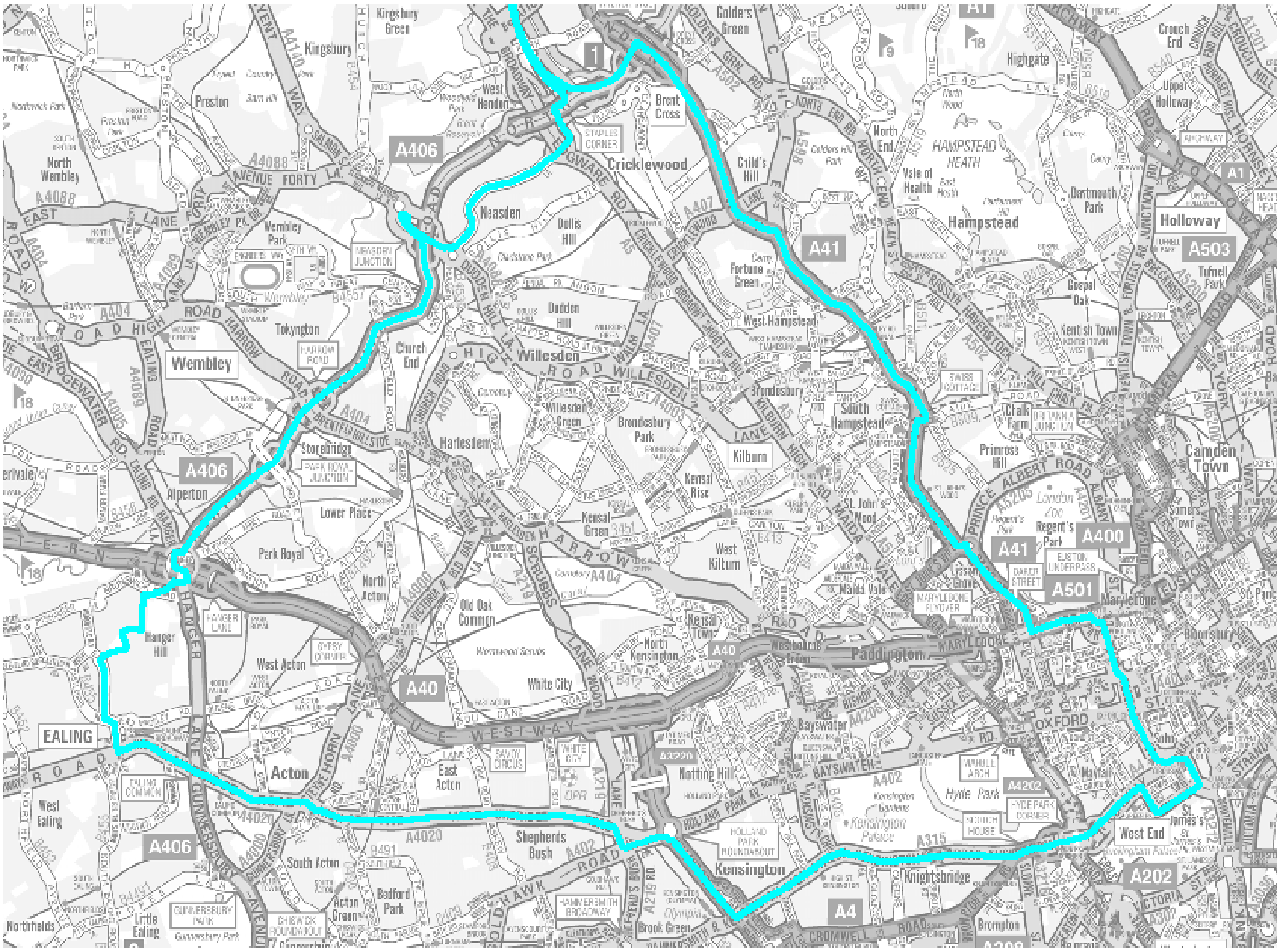


Figure 3 shows the speed trace for the London Passenger Car drive cycle. At 2,400 seconds, it is twice as long as the NEDC with far more transient vehicle speeds (acceleration/deceleration). The drive cycle distance is more than doubled at 26.34km compared with the 11km of the NEDC. Most importantly, the cycle is derived from actual driving conditions in London.

Figure 3 TfL Passenger Car Drive Cycle speed trace.

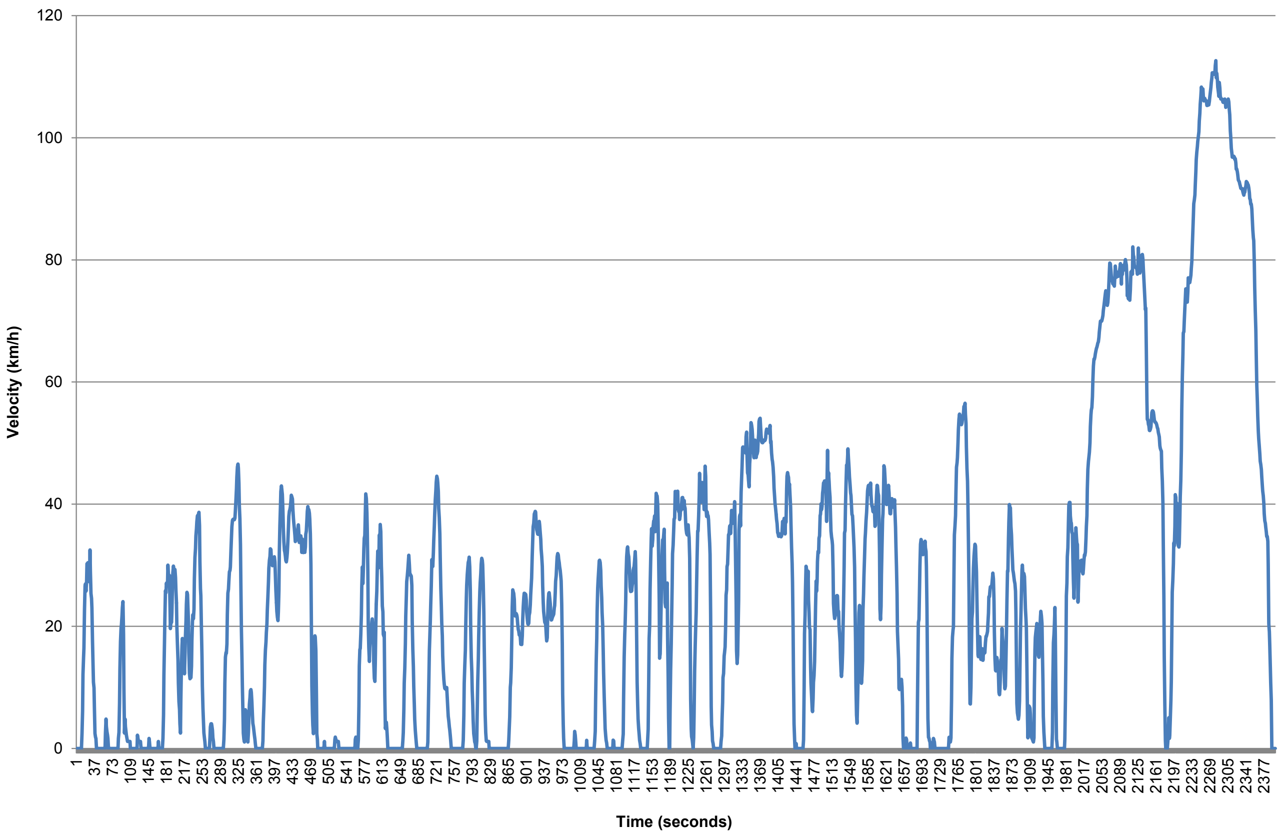


Table 2 TfL Passenger Car Drive cycle metrics.

Cycle Phase	Description	Time (secs)	Distance (km)	Avg spd (km/h)
Phase 1	Urban	1656	8.38	18.2
Phase 2	Suburban	528	4.69	32
Phase 3	Motorway	216	4.48	74.8
Total	-	2400	17.56	26.34

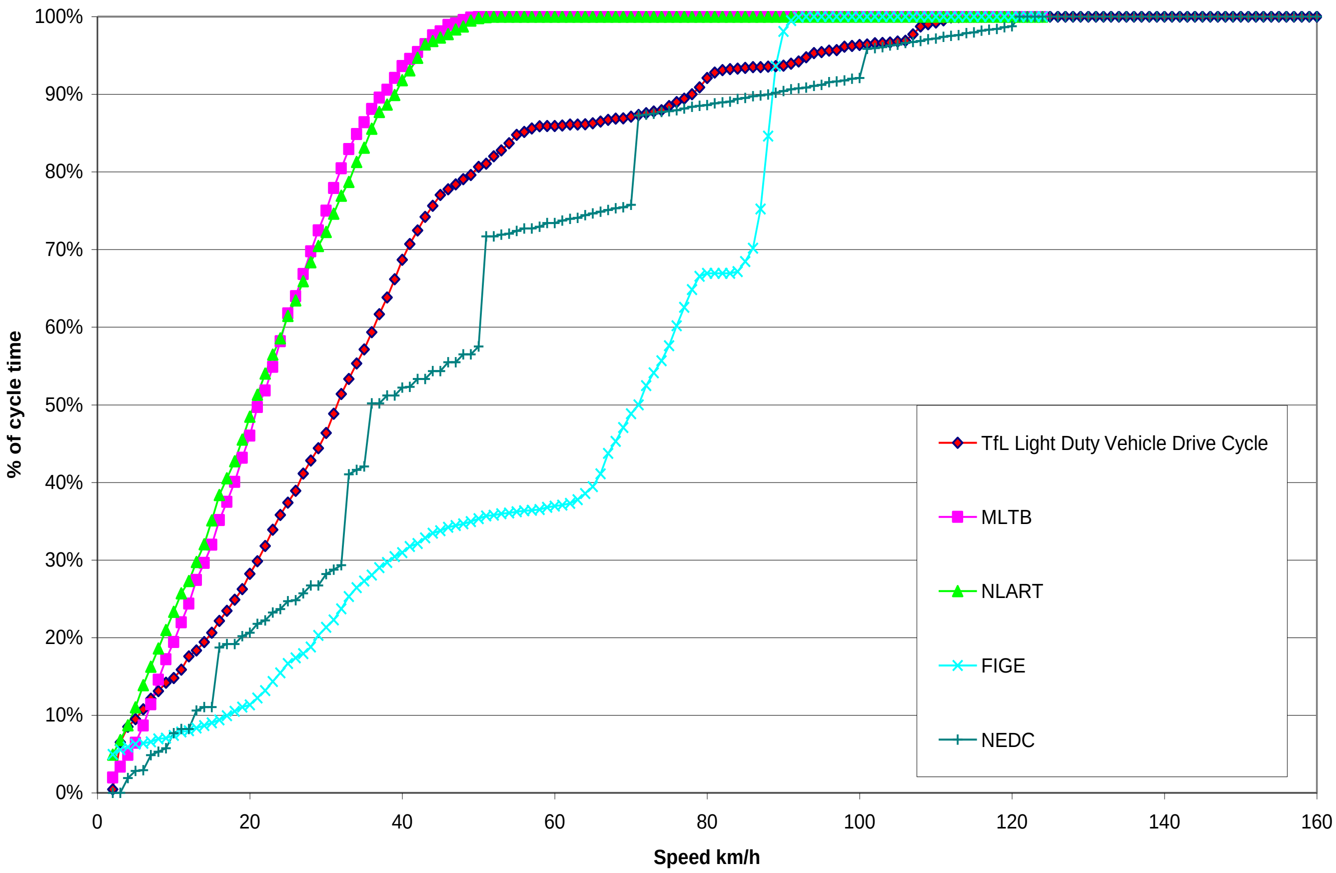
By way of comparison, it is interesting to note that the Urban phase of the TfL Passenger Car Cycle closely matches the measured traffic speeds in Central & Inner London, falling in the middle of the range 14 – 22 km/h. The Suburban phase closely matches the range of speeds measured in Outer London, falling within the range of 30 – 35 km/h. (see Travel in London report 3, Figure 4.1). This provides comfort that the route choice, data logging and drive cycle definition have captured representative driving conditions in London.

It is easy to see that this new cycle is far more transient than the NEDC cycle illustrated in figure 1. This reflects the more 'stop-start' driving conditions on London roads compared with the standardised European cycle (NEDC). A more detailed comparison is possible by consideration of the following charts showing firstly, cumulative speed, and secondly, cumulative acceleration on a variety of recognised drive cycles.

4. Test cycle analysis and comparison with other cycles

To show how representative the London Passenger Car cycle is, a comparison has been carried out by plotting the overall speed and acceleration histograms for a range of cycles, including several London based driving cycles and the legislative European cycle (NEDC). The cumulative speed chart in figure 4 gives an overall impression and comparison of the cycle speed profile. The TfL cycle falls in the middle of the range of cycles shown.

Figure 4 Comparison of cumulative speeds

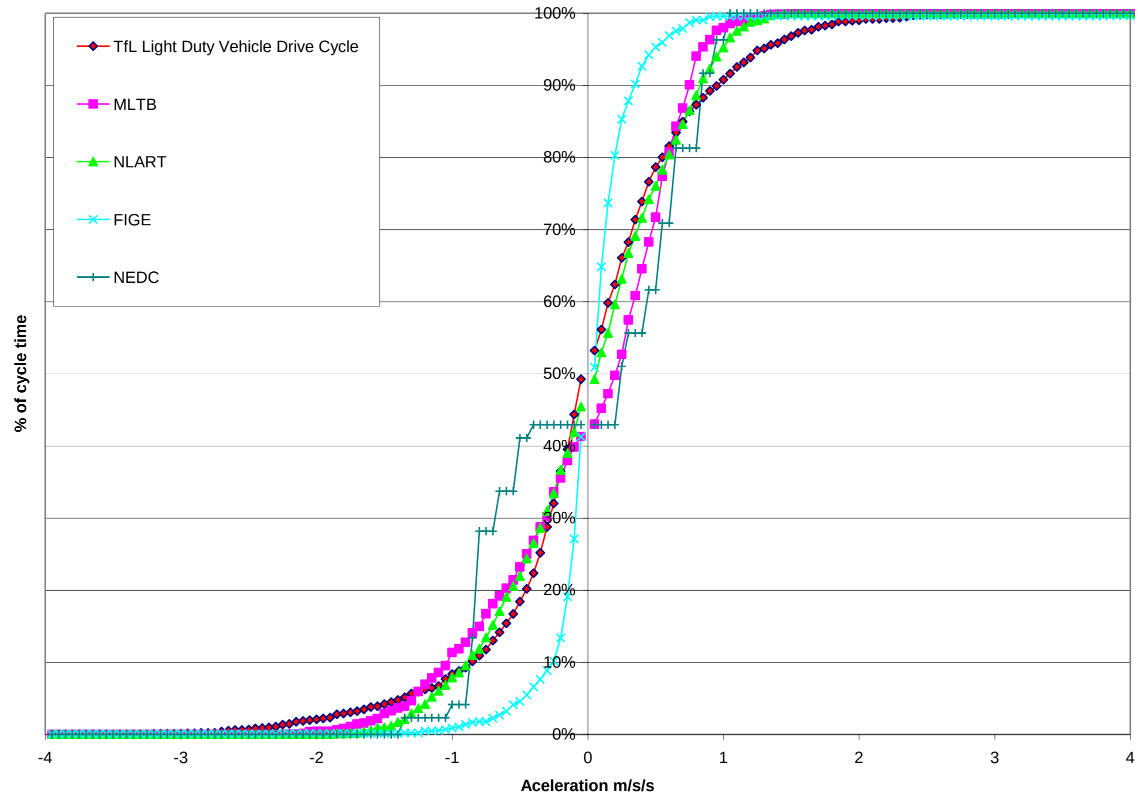


The HGV cycle, NLART (North London Articulated Road Transport) and bus cycle MLTB (Millbrook London Transport Bus), both derived from data-logging vehicles in London, show a lower overall speed but very similar overall pattern.

The FIGE heavy truck cycle (a representation of the European Transient Cycle produced for chassis dynamometer testing by the former FIGE Institute, Archen, Germany) incorporates both rural driving and motorway operation, which biases the cycle above 60km/h.

Since most emissions are formed under vehicle acceleration, it is perhaps even more meaningful to compare the acceleration profile of the drive cycle with those of others. Figure 5 below compares the overall acceleration profile of the cycle with other established test cycles. This gives us a broad picture of the driving style for a cycle. A very steep rise indicates very low rates of acceleration and deceleration or very smooth driving. Conversely a flatter curve shows a more aggressive driving pattern. In this comparison, the TfL cycle features higher rates of acceleration and deceleration than is seen in cycles defined for heavier vehicles. This is caused by a number of factors. Firstly, the TfL Passenger Car drive cycle speed trace features a high degree of transience that was data-logged as a representation of vehicle behaviour in London for light-duty vehicles. The second point to note from figure 5 is that drive cycles developed specifically for heavy-duty vehicles (eg FIGE) tend to have more gentle acceleration and deceleration, given the greater inertia of those vehicle types. This is significant for future testing of heavy-duty vehicles by TfL as some of these vehicles may be incapable of following the prescribed speed trace.

Figure 5 Comparison of cumulative acceleration.



5. Drive cycle validation

The first objective of the drive cycle validation was to confirm that the draft TfL Passenger Car Drive cycle was driveable under laboratory conditions. Occasionally, for technical reasons (e.g. lack of power, high vehicle inertia, limitations in brake performance) it may not be possible for a vehicle to match a drive cycle trace. For this reason the cycle was verified using a representative vehicle.

A Euro 4, Vauxhall Astra 1.4L petrol was supplied by Millbrook Proving Ground for the test. The vehicle was prepared and tested as per the European Directive 70/220EC as amended, with the exception of the drive cycle and the ambient temperature.

During the verification tests, the vehicle was able to follow the speed trace accurately demonstrating that the drive cycle is workable. At the same time, the emissions were sampled from the vehicle both to validate the emissions sampling set-up and to measure the emission levels under the test scenarios described below. It should be remembered that the tests described below are for a single vehicle and therefore the outcome cannot be generalised. However, comparisons made using the same vehicle are valid.

6. Exhaust emission test procedure

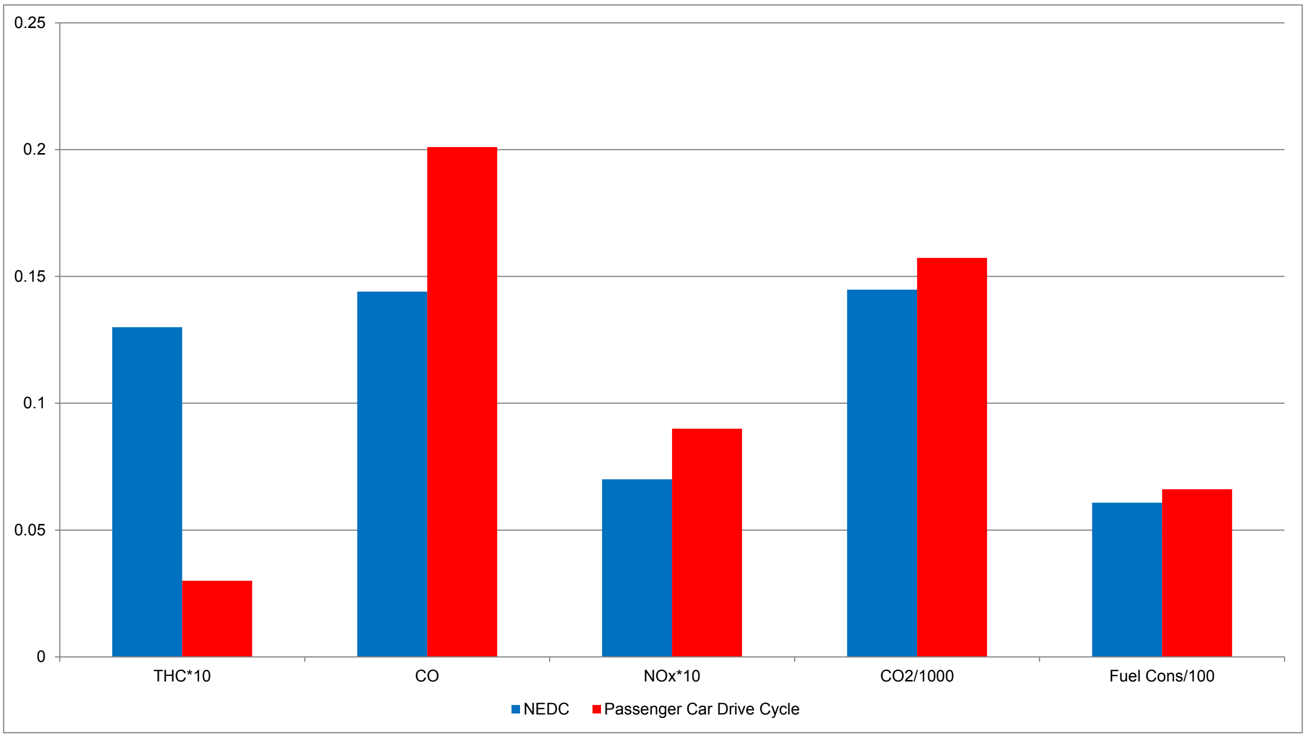
As part of this programme, it was necessary to define a procedure for emissions testing to ensure that testing at any time in the future is conducted in a consistent way that will produce comparable results. The test procedure is based upon the procedure used for type approval emissions testing, as defined in Directive 70/220/EC, but adapted to suit the needs of this programme. Testing is conducted on a chassis dynamometer (a carefully calibrated rolling road, where the emissions are sampled for analysis) under laboratory conditions and this procedure allows for control of as many variables as possible. Some allowance is made for use of vehicle ancillary systems, with a "mid-range" load being selected.

The following section looks at some initial comparisons of emissions performance arising from the drive cycle validation.

7. Comparison of NEDC and TfL drive cycles

The first test conducted using the new drive cycle was a comparison of the new cycle with the NEDC drive cycle used for type approval and all 'official' tests of fuel consumption and CO_2 emissions. The test was carried out at 23°C, in line with type-approval practice and from a hot start to understand the influence of the drive cycle on vehicle emissions. The comparison of these results can be seen in figure 6, below.

Figure 6 Comparison of emissions over the NEDC and TfL Passenger Car cycle from a hot start (test of a single vehicle).



Looking at Figure 6, it can be seen that the drive cycle does have a significant effect on the vehicle emissions performance. In order to fit all measures onto a single chart, the values for NO_x have been reduced by a factor of 10, the CO_2 by a factor of 1000 and the fuel consumption by a factor of 100. This means that the values for HC, CO and NO_x are, relatively, very small and therefore whilst the percentage changes may look significant (-72.5 per cent, 39.6 percent and 20 per cent respectively), in true mass emission terms they are not large.

CO_2 was found to be 12.6 g/km (8.7 per cent) higher over the TfL Passenger Car cycle than the NEDC and fuel consumption was seen to also increase by 8.7 per cent. This would appear to be a significant difference caused by the change in the transient nature of the London Passenger Car drive cycle compared with the NEDC. This gives some indication of the level of under-representation of real driving emissions seen in type-approval testing compared with urban driving observed in London.

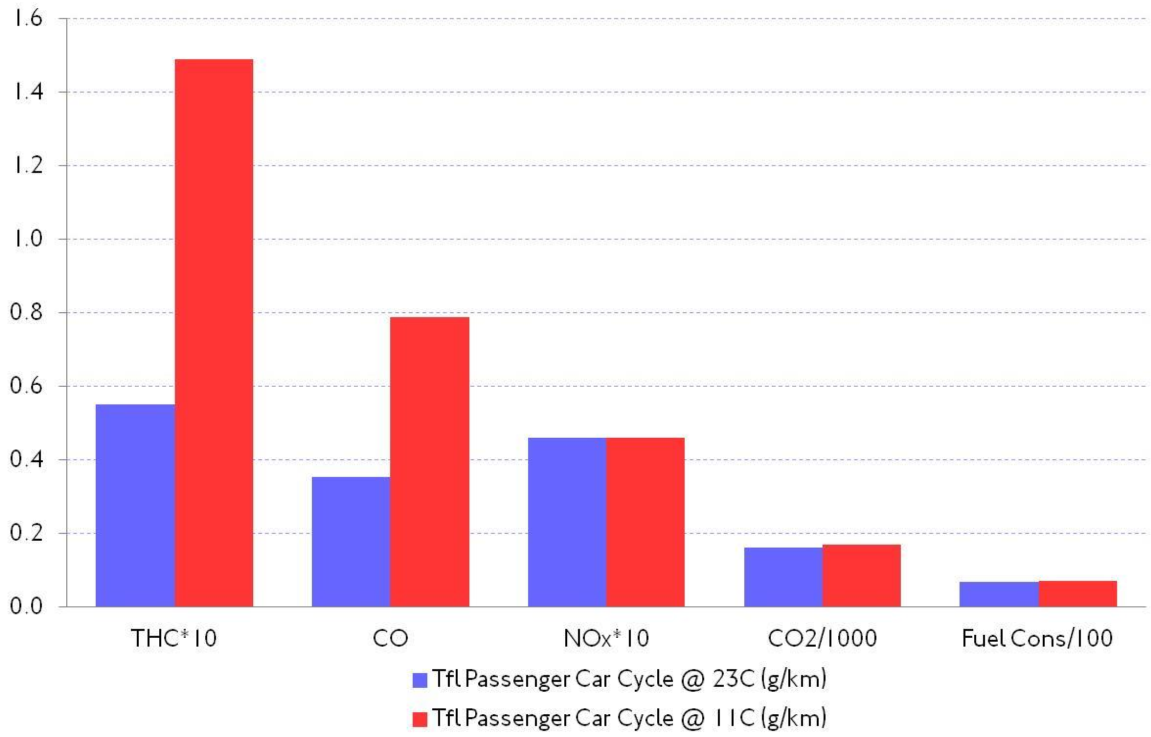
8. Comparison of cold start emissions using the TfL drive cycle

A second, but equally important objective was to understand the effect ambient air temperature has on exhaust emissions and fuel economy. The average ambient temperature in London is 11°C compared to nominally 23°C (in the range 20-30°C) for European Directive emissions tests. As the majority of emission laboratories are designed to meet the 20-30°C criteria it was important to understand and quantify any influence ambient temperature has on exhaust emissions over this newly derived test cycle. Therefore, a cold and hot start test was performed at both 11°C and 23°C.

Firstly the vehicle was tested over the TfL Passenger Car cycle from a cold start at both 11°C and 23°C to assess the effect of ambient temperature on exhaust emissions with a cold engine. The testing was then repeated at the same ambient temperatures with the vehicle operating with a fully warm engine.

The tests were carried out with no repeats and therefore no statistics can be used to ascertain the confidence level in any changes between the results. However the results can be used to gain an indication on the likely affects of the ambient temperature on the emissions performance of the vehicle. It should be noted that different vehicles and fuels may give a different result for each condition and hence the overall effect may change.

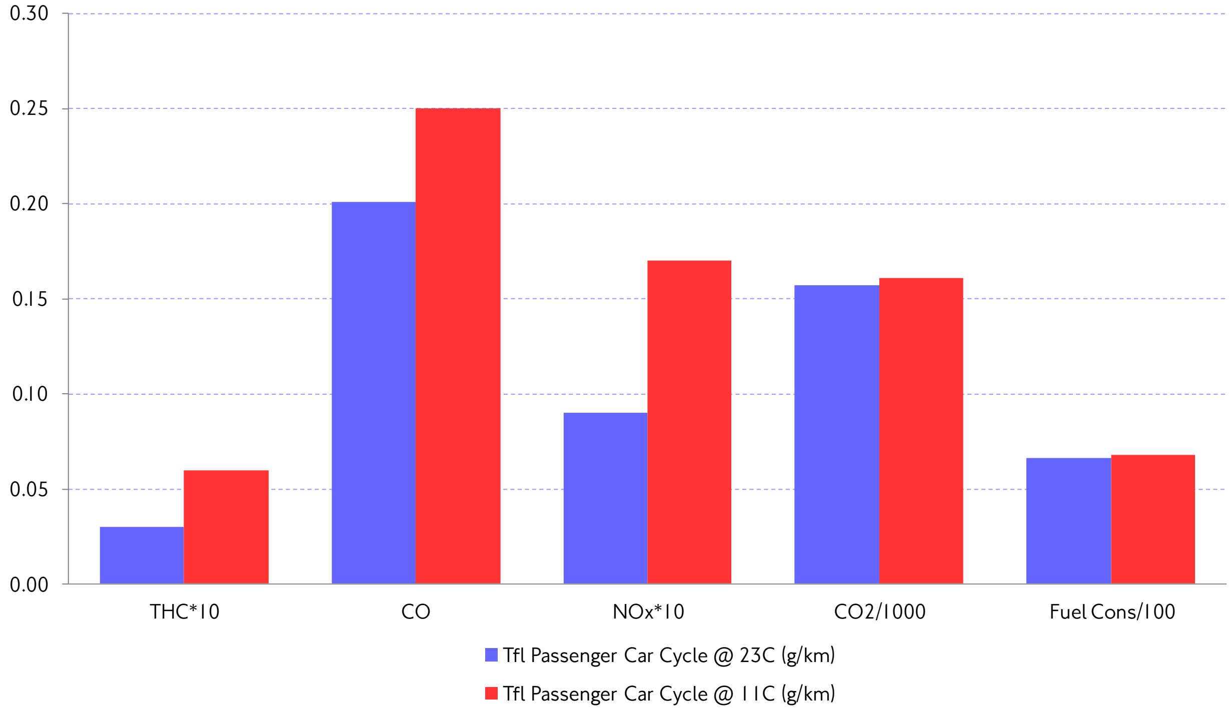
Figure 7 Comparison of emissions at 11°C and 23°C from a cold start.



From figure 7, it can be seen that there is an indication that ambient temperature does affect the vehicle emissions performance. At 11°C, HC and CO were seen to increase by 170.9 per cent and 123.2 per cent respectively compared to the test at 23°C, however no change was noted in NO_x emissions. CO_2 was found to be 6 g/km (3.7 per cent) higher at 11°C than at 23°C and fuel consumption was seen to increase by 4.3 per cent.

These results are probably to be expected as the emissions of HC, CO and NO_x are, for the most part, controlled by the exhaust catalyst (3-way catalytic convertor) which must reach a 'light off' temperature before it is fully efficient. At 11°C it will take slightly longer to achieve this temperature and therefore will emit more emissions prior to 'light off'. With regard to CO_2 and Fuel Consumption the colder ambient temperature is likely to lead to higher oil viscosity and friction in the engine meaning the engine has to work harder to achieve the same power output, resulting in the consumption of more fuel and the creation of additional CO_2.

Figure 8 Comparison of emissions at 11°C and 23°C from a hot start.



Looking at Figure 8, it can be seen that there is an indication that ambient temperature also affects the vehicle emissions performance from a hot start. At 11°C, HC, CO and NO_x were seen to increase by 73.3 per cent, 24.4 per cent and 89.4 per cent respectively compared to the test conducted at 23°C. However, as described above, it should be noted that the absolute values are very low for these pollutants especially HC and NO_x and therefore even a small g/km change will lead to a high percentage change. Therefore in real terms the changes are insignificant. CO_2 was found to be 3.9 g/km (2.5 per cent) higher at 11°C than at 23°C and fuel consumption was seen to increase by 2.6 per cent.

This evaluation of the effects of ambient temperature reveals that the difference between 11°C and 23°C has very little effect. The difference that can be observed is probably explained by the time that is taken for the exhaust catalyst to achieve 'light off' temperature being slightly extended at lower ambient temperature. The most revealing effect is that of CO_2 emissions, which pertain to fuel consumption too. These show an increase of 2.5 per cent at the lower temperatures compared with an increase of 8.7 per cent as a result of the drive cycle. This means that the drive cycle has a much greater influence on greenhouse gas emissions than the ambient temperature.