Appendix 3
Determination of the origins of excess NO_X emitters and their repair

Contents

1. The issues

Some conclusions from the JCS study into *The inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency* [1] as distilled out and reported in the Phase 1 report of this programme[2] are:

- the (surprisingly?) high number of vehicles whose emissions are above the NO_X standard,
- the fraction of excess NO_X emitters appears to be independent of the vehicle sample and the state of maintenance, with maintained vehicles having emissions nearly identical to those before maintenance,
- the reasons for the high proportion of excess NO_X emitters, and its insensitivity to maintenance, is not currently known.

These conclusions are of concern, particularly within the context of NO_2 being a challenging pollutant for the UK meeting its air quality targets. They also raise a number of issues, discussed in Section 4 of the main report. One was that if maintenance did not reduce NO_X emission then the cost effectiveness of possible NO_X testing is questionable despite its desirability from the air quality stance. It was hypothesised that contrary to the JCS findings appropriate maintenance would reduce NO_X emissions.

This hypothesis was tested in two ways, firstly by a practical study, and secondly by analysing some US data.

An aspect of the current in-service tailpipe emissions test that was highlighted in the Phase 1 report[2] was regarding vehicles which failed the test because λ was too high, i.e. greater than 1.03 or the manufacturer declared limits if applicable. The emissions performance of such vehicles over the type approval drive cycle was not known. It was hypothesised that these might be excess NO_X emitters and that the current test was successfully identifying some defective vehicles and requiring that they were repaired. Practically it was hoped to identify a/some such vehicle(s) and to test the above hypothesis.

---

[1] The inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency – Main Report, EC DGs for Environment (DG XI) Transport (DG VII) and Energy (DG XVII), LAT AUTh INRETS TNO TÜV Rheinland and TRL, May 1998

[2] An in-service emissions test for spark ignition petrol engines – Phase 1 report: Definition of an excess emitter and effectiveness of current annual test, J Norris, PPAD/9/107/09, AEA Technology report AEAT/ENV/R/0679, June 2001.

2. Experimental programme

2.1 INTRODUCTION

This small experimental programme was designed to test two hypotheses:

1. that the maintenance of vehicles with excessive NO_X emissions can reduce NO_X emissions, and
2. that vehicles failing the current in-service emissions test because $\lambda > 1.03$ (or manufacturer declared limit) are excess NO_X emitters.

2.2 TEST PROGRAMME

To test hypothesis 1 the test programme was:

- identify 6 high mileage vehicles that might be high NO_X emitters,
- measure their regulated emissions over several pertinent driving cycles,
- identify those vehicle that emit over the type approval standard,
- change oxygen sensor,
- retest,
- change catalyst, and
- retest.

Each set of measurements was preceded by, as a minimum, the EPEFE preconditioning protocol of an ECE + 2× EUDC. Emissions were usually measured over the second EUDC conditioning cycle, and then compared with those measured during this portion of the cold and hot start measurement cycles. This enabled the stability of a vehicle's emissions to be assessed.

Some characteristics of the vehicles tested are given in Table A3.1.

Table A3.1 Some characteristic of the vehicles tested

Label	Make	Engine size (litres)	Recorded mileage	Registration letter, year	Emissions specification
Vehicle 1	Manufacturer 1	1.8	70,000	V, 1999	Euro II
Vehicle 2	Manufacturer 2	1.4	85,000	L, 1993	Euro I
Vehicle 3	Manufacturer 3	1.8	157,000	L, 1993	Euro I
Vehicle 4	Manufacturer 4	1.5	153,000	P, 1996	Euro I
Vehicle 5	Manufacturer 5	1.8	91,000	K, 1992	Euro I
Vehicle 6	Manufacturer 2	1.6	99,000	N, 1996	Euro I

The driving cycles were selected so as to measure NO_X emissions for the vehicles' type approval cycle and at a steady speed where significant NO_X emissions might be expected. For the latter several possibilities were considered, including an ARTEMIS motorway cycle and the WSL Motorway (113 kph) cycle. However, experience from an earlier project for the DfT (Ethanol Emissions Testing, PPAD 9/107/15) led to the selection of a steady speed (120 kph) only taking emissions measurements when the vehicle, and its emissions, were stable. This eliminates preconditioning or warm up effects which the earlier experiences showed can be dominant.

The test matrix used was:
1. cold start regulatory ECE + EUDC i.e. Euro I/Euro II cycle (these are the same),
2. hot start regulatory ECE + EUDC,
3. steady speed 50 kph,
4. steady speed 120 kph,
5. in-service MOT dual idle speed test, including NO_X measurement.

2.3 RESULTS FOR VEHICLES IN THEIR AS RECEIVED STATE

Tables A3.2 to A3.6 give the results for the regulated emissions over the 5 driving cycles listed above.

NO_X emissions limits are not explicitly given for the Euro I and Euro II standards, rather it is limits for NO_X+HC emissions. However, Directive 98/69/EC does specify limits for these two species separately for later emissions standards. If this HC:NO_X ratio is applied to the Euro I and Euro II NO_X+HC emission limits of 0.97 and 0.50 g/km, respectively, then NO_X emissions limits of 0.42 and 0.21 g NO_X/km can be derived. In Table A3.2 the NO_X, CO and HC emissions are expressed both in absolute terms (g/km) and as a percentage of the limits appropriate to the vehicle.

Table A3.2 Regulated emissions for vehicles as received for cold start ECE + EUDC cycle

	CO_2 (g/km)	CO (g/km)	NO_X (g/km)	HC (g/km)
Vehicle 1	163.4	1.111 (40.9%)	0.310 (144.4%)	0.197 (69.0%)
Vehicle 2	147.8	2.005 (73.7%)	0.161 (38.8%)	0.131 (23.6%)
Vehicle 3	195.2	2.696 (99.1%)	0.635 (152.7%)	0.206 (37.2%)
Vehicle 4	160.6	2.212 (81.3%)	0.317 (76.4%)	0.232 (41.9%)
Vehicle 5	176.1	4.524 (166.3%)	0.106 (25.5%)	0.219 (39.5%)

Table A3.3 Regulated emissions for vehicles as received for hot start ECE + EUDC cycle

	CO_2 (g/km)	CO (g/km)	NO_X (g/km)	HC (g/km)
Vehicle 1	149.3	0.505	0.426	0.125
Vehicle 2	142.6	1.812	0.112	0.059
Vehicle 3	180.6	0.804	0.609	0.072
Vehicle 4	147.3	2.763	0.260	0.135
Vehicle 5	157.0	3.486	0.061	0.105
Vehicle 6	147.0	1.189	0.143	0.087

Table A3.4 Regulated emissions for vehicles as received for steady 50 kph

	CO_2 (g/km)	CO (g/km)	NO_X (g/km)	HC (g/km)
Vehicle 1	93.2	0.155	0.002	0.046
Vehicle 2	87.6	0.039	0.003	0.013
Vehicle 3	110.4	0.191	0.222	0.067
Vehicle 4	88.8	0.049	0.073	0.028
Vehicle 5	84.3	0.469	0.000	0.057

Table A3.5 Regulated emissions for vehicles as received for hot steady 120 kph

	CO_2 (g/km)	CO (g/km)	NO_X (g/km)	HC (g/km)
Vehicle 1	189.1	0.205	0.073	0.205
Vehicle 2	151.6	0.349	0.385	0.038
Vehicle 3	199.9	0.063	1.359	0.021
Vehicle 4	177.3	0.495	0.371	0.016
Vehicle 5	180.8	0.913	0.091	0.090

Table A3.6 Regulated emissions for vehicles as received for MOT test

	high idle CO (%)	high idle λ	high idle NO_X (ppm)	high idle HC (ppm)
Vehicle 1	0.049	0.998	1.2	16
Vehicle 2	0.010	1.006	110	33
Vehicle 3	0.018	1.002	139	24
Vehicle 4	0.070	1.004	36.9	20
Vehicle 5	0.105	0.998	36.8	17
Vehicle 6	0.054	0.998		70
	low idle CO (%)	low idle λ	low idle NO_X (ppm)	low idle HC (ppm)
Vehicle 1 - 15 s (after 2 minutes)	0.005 (0.007)	1.000 (1.020)	0.6 (21.0)	29 (9)
Vehicle 2	0.006	1.000	3.9	31
Vehicle 3	0.016	1.004	38.6	24
Vehicle 4	0.026	1.002	0.8	26
Vehicle 5	0.128	0.996	0.7	20
Vehicle 6	0.067	0.998		82

It should be remembered that the objective of this work is to identify, and to attempt to repair excess NO_X emitters. Tables A3.2 to A3.6 contain a wealth of data, some of which is discussed further in other sections of the report. However, much of this data is simply reported without comment here.

Table A3.2 (and Table A3.3) demonstrate the widely accepted observation that cold starting leads to a smaller increase in NO_X emissions than for CO and HC. The test programme was curtailed for the last vehicle tested, vehicle 6, because after analysing its emissions from the hot start ECE+EUDC cycle, and given the low sensitivity of NO_X emissions from cold starts, it was apparent that its NO_X emissions were well below the derived Euro I threshold limit of 0.42 g/km. Notwithstanding, from Table A3.2 it is seen that two vehicles do emit significantly above their type approval limits, Vehicles 1 and 3.

Table A3.7 Regulated emissions for vehicle 3 as received and after maintenance

	CO_2 or λ	CO	NO_X	HC
As received				
cold start ECE+EUDC	195.2 g/km	2.696 g/km	0.635 g/km	0.206 g/km
hot start ECE+EUDC	180.6 g/km	0.804 g/km	0.609 g/km	0.072 g/km
steady speed 50 kph	110.4 g/km	0.191 g/km	0.222 g/km	0.067 g/km
steady speed 120 kph	199.9 g/km	0.063 g/km	1.359 g/km	0.021 g/km
MOT test high idle	1.002	0.018%	139 ppm	24 ppm
MOT test low idle	1.004	0.016%	38.6 ppm	24 ppm
With replacement oxygen sensor				
cold start ECE+EUDC	194.3 g/km	1.292 g/km	0.655 g/km	0.187 g/km
hot start ECE+EUDC	176.0 g/km	0.990 g/km	0.652 g/km	0.148 g/km
steady speed 50 kph	110.5 g/km	0.115 g/km	0.152 g/km	0.047 g/km
steady speed 120 kph	190.0 g/km	0.056 g/km	1.348 g/km	0.047 g/km
MOT test high idle	1.004	0.005%	145 ppm	0 ppm
MOT test low idle	1.000	0.007%	20.6 ppm	0 ppm
With replacement catalyst				
cold start ECE+EUDC	197.2 g/km	0.542 g/km	0.274 g/km	0.067 g/km
hot start ECE+EUDC	177.6 g/km	0.038 g/km	0.296 g/km	0.016 g/km
steady speed 50 kph	110.0 g/km	0.010 g/km	0.117 g/km	0.023 g/km
steady speed 120 kph	195.4 g/km	0.051 g/km	0.902 g/km	0.010 g/km
MOT test high idle	1.010	0.004%	113 ppm	18 ppm
MOT test low idle	1.000	0.001%	5.8 ppm	13 ppm

The test programme was described at the beginning of Section 2.2 of this appendix. Table A3.7 gives the emissions data for Vehicle 3 through the test programme. Changing the oxygen sensor only caused two significant changes in emissions – cold start CO emissions and to a lesser degree CO and HC emissions at 50 kph. Most significantly it caused negligible change in NO_X emissions over the drive cycles.

In contrast changing the catalyst did cause a reduction in NO_X emissions. The size of this varied for the different drive cycles, as is tabulated below.

cold start regulatory ECE + EUDC	-56.9%	
hot start regulatory ECE + EUDC	-51.4%	
steady speed 50 kph	-47.3%	
steady speed 120 kph	-33.6%	
in-service MOT normal idle test	-85%	} these data are not very precise because
in-service MOT high idle test	-19%	} of the nature of the measurement.

Without further embellishment it is clear from the data that for this vehicle appropriate maintenance did reduce NO_X emissions by between 55 and 60% over the type approval drive cycle.

Table A3.8 gives analogous data for Vehicle 1.

Table A3.8 Regulated emissions for vehicle 1 as received and after maintenance

	CO_2 or λ	CO	NO_X	HC
As received				
cold start ECE+EUDC	163.4 g/km	1.111 g/km	0.310 g/km	0.206 g/km
hot start ECE+EUDC	149.3 g/km	0.505 g/km	0.426 g/km	0.072 g/km
steady speed 50 kph	93.2 g/km	0.155 g/km	0.002 g/km	0.067 g/km
steady speed 120 kph	189.1 g/km	0.205 g/km	0.073 g/km	0.021 g/km
MOT test high idle	0.998	0.049%	139 ppm	24 ppm
MOT test low idle	1.000/1.020	0.005%	38.6 ppm	24 ppm
With replacement oxygen sensor				
preconditioning hot start ECE+EUDC	156.2 g/km	1.090 g/km	0.879 g/km	0.239 g/km
hot start ECE+EUDC	145.2 g/km	6.716 g/km	0.715 g/km	0.313 g/km
With original oxygen sensor reinstated				
preconditioning hot start ECE+EUDC	148.7 g/km	0.664 g/km	0.616 g/km	0.067 g/km
cold start ECE+EUDC	163.5 g/km	1.169 g/km	0.306 g/km	0.181 g/km
With original oxygen sensor and new catalyst				
cold start ECE+EUDC	165.1 g/km	0.563 g/km	0.188 g/km	0.048 g/km
hot start ECE+EUDC	147.1 g/km	0.109 g/km	0.381 g/km	0.017 g/km
repeat hot start ECE+ EUDC (very smooth)	146.1 g/km	0.217 g/km	0.243 g/km	0.041 g/km
repeat hot start ECE+ EUDC (less smooth)	153.0 g/km	0.1589 g/km	0.452 g/km	0.036 g/km
steady speed 50 kph	101.0 g/km	0.017 g/km	0.001 g/km	0.017 g/km
steady speed 120 kph	174.1 g/km	0.026 g/km	0.719 g/km	0.009 g/km
repeat steady speed 120 kph			0.30 g/km	
2nd repeat steady speed 120 kph			<0.02 g/km	

It rapidly became apparent that the emissions performance of this vehicle deteriorated when it was fitted with a new oxygen sensor. The hot start ECE+EUDC data were collected after considerable preconditioning and mixed driving (>60 miles) to eliminate the possibility of the ECU not having "learnt" the characteristics of the new oxygen sensor.

Ultimately a franchised dealer tried to diagnose the fault using an OEM diagnostic fault code reader. No faults were recorded within the ECU. When being driven, however, the live readings revealed that on acceleration fuel pulse widths increased briefly from 2 – 3 ms to around 8 ms. This is consistent with the time resolved, modal, emissions data collected. No further explanation for the origins and mechanism of this fault was found beyond it being attributed to a faulty oxygen sensor. A replacement oxygen sensor was ordered.

The franchised dealer's stores manager commented that this was the first time they had had to reject a replacement oxygen sensor. However, it is noteworthy that the driveability of the vehicle, and the OEM diagnostic fault code reader, gave no indication of there being a problem. Neither did the MOT type emissions measurements. It was only the combination of a chassis dynamometer and sophisticated emissions analysis that revealed there was a significant in-use pollution problem from the vehicle when fitted with the new oxygen sensor.

Because of the delivery time of a new oxygen sensor and scheduling constraints this was never fitted. Instead the original oxygen sensor was refitted. The data in Table A3.8 shows the emissions over the cold start ECE+EUDC test returned to their original values.

A new catalyst was fitted (with the original oxygen sensor retained). Overall this did reduce CO and HC emissions, especially for cold starting, but it made little difference to NO_X emissions.

Acting on an intuitive feeling that poor emissions performance was associated with "transients", several hot start ECE+EUDCs were driven with ranging from very high attention to no attention being devoted to restricting movement of the accelerator pedal. This led to variations in the NO_X emissions averaged over the cycle of virtually a factor of two.

An even more extreme example of this variability occurred when running at the steady speed of 120 kph. It was noted that NO_X concentrations from the vehicle, fitted with the new catalyst, were around ten times higher than the values measured originally. The vehicle was braked to stationary, and then accelerated back to a steady speed of 120 kph within 3 minutes. The NO_X emissions were observed to have fallen from around 0.7 g/km to <0.02g/km. The vehicle was slowed to around 15 kph, and the accelerated back to 120 kph. This time the NO_X emissions were around 0.3 g/km.

Overall this vehicle can be categorised as an excess NO_X emitter for which the maintenance undertaken did not reduce its NO_X emissions. However, the team are convinced that the vehicle was faulty, and that appropriate diagnosis and rectification would have reduced emissions.

2.4 MOT FAILING VEHICLE WITH LAMBDA > 1.03

To test hypothesis 2, namely that vehicles failing the current in-service emissions test because $\lambda > 1.03$ (or manufacturer declared limit) are excess NO_X emitters, the test programme designed was:

- identify vehicle(s) that have failed their annual MOT test because $\lambda > 1.03$,
- measure their emissions for MOT test (to confirm the failure and to obtain baseline values),
- measure their regulated emissions over the type approval drive cycle,
- repair them,
- retest to show that they now can pass the MOT test,
- retest over the type approval drive cycle to quantify the change in emissions caused by their repair.

Only one vehicle of this type was identified. It was a 1.6 litre Peugeot 405, made in 1994, with around 82,000 miles on its odometer. For this vehicle, whose engine code began BFZ, the manufacturer declared upper λ limit was 1.15, rather than the more commonly encountered 1.03[3].

Table A3.9 gives the results of the MOT test when the vehicle initially failed. The very high λ value was confirmed for its "as received" state at our test facility.

Table A3.9 MOT test reults before and after repair

	Initial MOT test results			Final MOT test results		
	Fast idle 1	Fast idle 2	Low idle	Fast idle 1	Fast idle 2	Low idle
CO	0.00%	0.00%	0.00%	0.019%	0.023%	0.021%
HC	13 ppm	13 ppm		24 ppm	27 ppm	35 ppm
λ	1.226	1.216		1.008	1.006	1.002
revs /min	2988	3097	849	2988	3097	849

The vehicle was tested over its type approval cycle, the ECE + EUDC test. The regulated emissions are listed in Table A3.10. Also included in this table are the Euro 1 limits and those derived for HC and NO_X separately, see second paragraph of Section 2.3 of this Appendix. Surprisingly given the MOT test results, the vehicle's CO emissions were above its type approval standard by nearly a factor of two whilst HC and NO_X emissions were within the standard. Examination of the time resolved emissions suggested that it was over-fuelling.

Table A3.10 Regulated emission over ECE + EUDC test before and during repair

CO_2	CO	HC	NO_X	$HC+NO_X$
Emissions for vehicle in its as received state				
194.1 g/km	5.132 g/km	0.323 g/km	0.258 g/km	0.582 g/km
Emissions for vehicle after replacing oxygen sensor and catalyst				
189.2 g/km	4.853 g/km	0.412 g/km	0.335 g/km	0.747 g/km
Euro I emissions standards (derived for HC and NO_X)				
	2.72 g/km	0.55 g/km	0.42 g/km	0.97 g/km

It was noticed that the catalyst appeared to have melted a little. Consequently the oxygen sensor and the catalyst were replaced and the vehicle was re-tested. Its regulated emissions changed little, see Table A3.10.

Consultation with a franchised dealer led to the recommendation that the vehicle's ECU should be changed. This was done by the franchised dealer. Detailed inspection of the ECU removed revealed that the "chip" was for a 2.0 litre Peugeot 405, i.e. it appears the vehicle had been tampered with and the over-fuelling was a consequence of the vehicle fuel map setting being for an engine 20% larger. Under these conditions one would expect the output from the oxygen sensor to adjust the fuel trim (reducing fuelling) to the bottom end of the range available, but that still being insufficient adjustment to prevent over-fuelling.

[3] In-service exhaust emission standards for road vehicles, VI, 7th Edition (Aug 2001)

The MOT test results of the vehicle with a new oxygen sensor, catalyst and ECU are given in Table A3.9. These show that the vehicle is now well within its specification. Unfortunately the vehicle was not available for a further cold start Euro I type I test, but given the diagnosis, the repairs undertaken and its original emissions test results, it is confidently anticipated that this vehicle would now meet its type approval emissions standards.

In conclusion, for this vehicle which failed the MOT test on high λ, NO_X emissions levels were not above their TA limit values over the type I test. However, the MOT test did correctly identify a vehicle whose emissions were outside those for an "appropriately maintained" vehicle and the subsequent vehicle repair resulted in reduced pollutant emissions.

This experience also illustrates how one needs to be cautious when inferring on-the-road emissions from emissions at idle. The results from this single vehicle do not totally disprove the starting hypothesis, but it at least requires modifying to become: **some** vehicles failing the current in-service emissions test because $\lambda > 1.03$ (or manufacturer declared limit) are excess NO_X emitters. Further research is required to confirm or disprove this amended hypothesis.

3. Analysis of EPA data

3.1 OBJECTIVES

An alternative strategy to undertaking an experimental programme to investigate how NO_X emissions might be reduced by appropriate repair and maintenance is, potentially, to analyse suitable, pre-existing data. Such a database has been found tabulated at the back of an EPA report[4].

This EPA study was an evaluation of OBD for use in detecting malfunctioning and high emitting vehicles. A principal objective was to obtain quantitative information on the reduction in emissions generated by an in-service roadworthiness test based on OBD inspection. (Further description and discussion of this report in the context of OBD in-service inspection are to be found in Reference 5.) Its approach was to test 201 vehicles, 194 whose MIL was illuminated and 7 high emitters that had no MIL illumination. The methodology used was:

- to identify and procure the vehicles to be tested,
- to measure their regulated emissions over the US type approval cycle, the FTP cycle,
- to measure their regulated emissions over the US in-service loaded test cycle, the IM240 test,

[4] Evaluation of on-board diagnostics for use in detecting malfunctioning and high emitting vehicles, E Gardetto and T Trimble, U.S. Environmental Protection Agency, EPA420-R-00-013, August 2000

[5] An in-service emissions test for spark ignition petrol engines – Phase 2a report: evaluation of the significance of ODB/OBM, J Norris and A Reading, PPAD/9/107/09, EMStec report EMStec/02/026, September 2002.

- to repair the vehicles following OEM published procedures (and in some cases in consultation with the OEM),
- to re-measure their regulated emissions over the FTP cycle,
- to re-measure their regulated emissions over the IM240 test.

The results of these emissions tests and the repairs undertaken form the database used for this analysis.

It is emphasised that this study, in contrast to the Phase 1 report (Reference 2), is not seeking to find the distribution of emissions from the vehicle parc. Rather it is to investigate how appropriate repair and maintenance might affect NO_X emissions. Therefore issues regarding how representative the vehicles selected are of the fleet as a whole are not relevant – the vehicles selected merely provide a source of potential excess emitters. It is also emphasised that care is required when attempting to apply conclusions from this database directly to the UK fleet. For example, the average engine capacity of the vehicles within this US database is 3.125 litres, and a significant fraction of these (estimated to be greater than 30%) are fitted with EGR. Both these details are significantly different from the average characteristic of the UK fleet. Despite these caveats, the database is very informative for this study.

3.2 DETAILED ANALYSIS

Figures A3.1 and A3.2 present the NO_X emissions data before and after maintenance in the style used by the JCS (reference 1). Figures A3.3 and A3.4 shown the equivalent data from the JCS study.

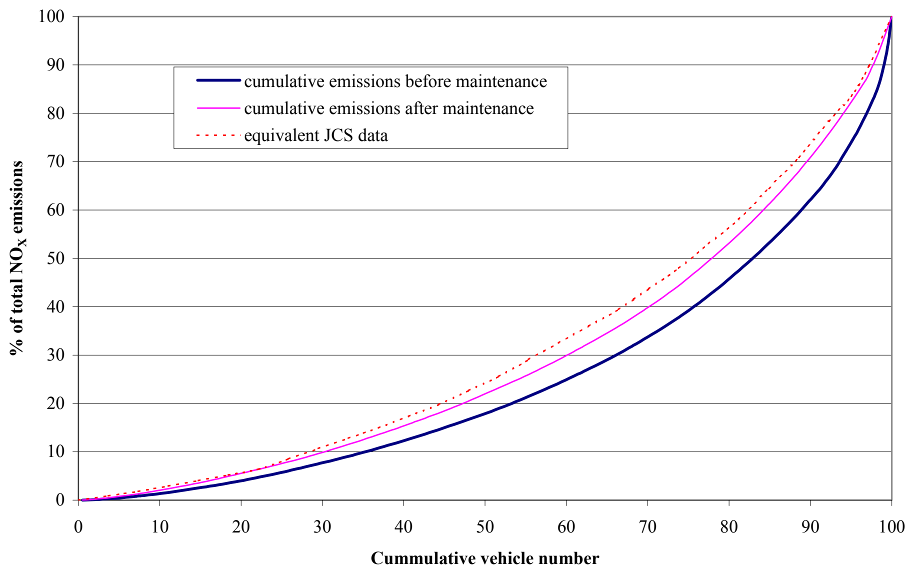

Figure A3.1 Percentage of total NO_X emissions for cumulative vehicle number for EPA data

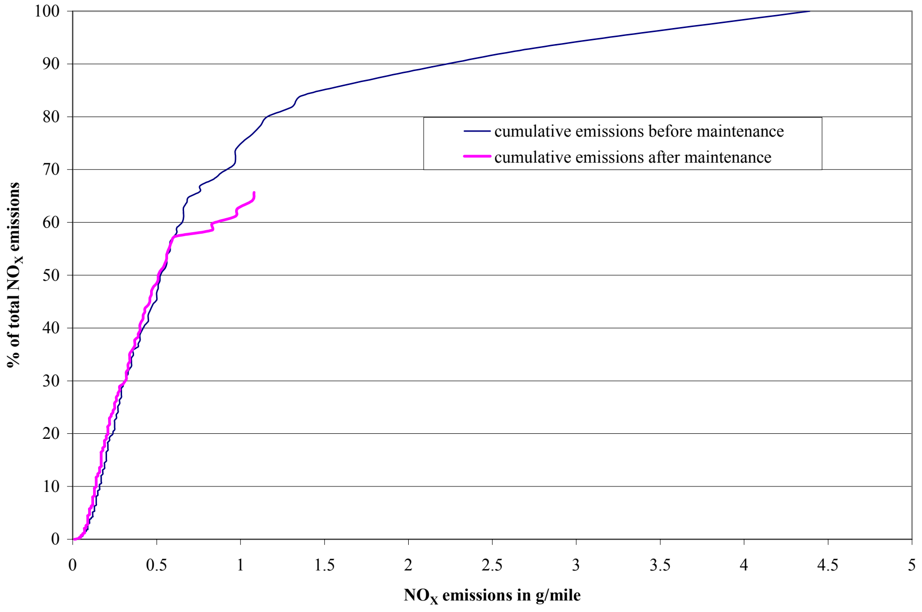

Figure A3.2 Percentage of total NO_X emissions against vehicular emission rate for EPA data

Figure A3.3 Percentage of total NO_X emissions for cumulative vehicle number for JCS data

Figure A3.4 Percentage of total NO_X and CO emissions against vehicular emission rate for JCS data

A fundamental conclusion from the JCS study was that NO_X emissions were not reduced by maintenance, in contrast to CO emissions which are also shown in Figure A3.4. Figure A3.2 indicates this is **not** the case. For the EPA study maintenance reduced NO_X emissions to 66% of their original value. (The equivalent figure for CO is 42%, whereas the JCS study found 60%, indicating some similarities between the two studies.)

For various reasons it was decided that no maintenance was required for 39 of the 199 vehicles tested in the EPA study. If the data for the remaining vehicles are analysed on a vehicle-by-vehicle basis, the change in NO_X emissions over the FTP cycle resulting from the maintenance can be calculated (in g/mile). These data are presented as a distribution in Figure A3.5, each column represents the number of vehicles whose emissions changed by ± 0.025 g/mile of the label on the ordinate.

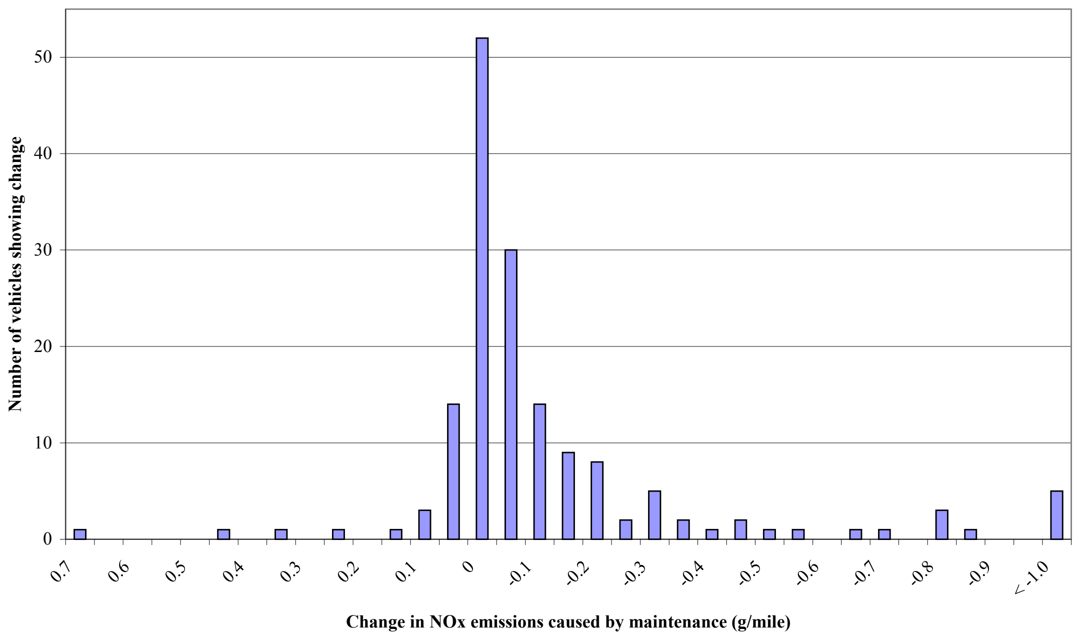

Figure A3.5 The distribution of the change in NO_X emissions caused by maintenance

Two important conclusions are evident from Figure A3.5:

- the reduction in emissions is not from a small minority of the vehicles tested, and
- repair and maintenance can cause NO_X emissions to increase (e.g. if a faulty EGR unit has stuck open, or if a fault led to over fuelling such that at this reducing stoichiometry NO_X emissions were low but CO and/or HC emissions were high).

From the data, maintenance cause the NO_X emissions of 105 vehicles to be reduced, of 41 vehicles to be increased, whilst there was no change for 14 vehicles. If negligible change in NO_X emissions is defined as a change between –0.025 and +0.025 g/mile, then 86 vehicles are classed as having reduced emissions, 22 as having increased emissions, and 52 vehicles showed no or only a small change, as per Figure A3.5.

The EPA data also contains information on the repairs undertaken. Table A3.11 lists the repairs undertaken, and the change in NO_X emissions over the FTP cycle for the 47 vehicles whose NO_X emissions reduced by ≥ 0.1 g/mile, and the 7 vehicles whose NO_X emissions increased by ≥ 0.1 g/mile. Further, the vehicles are ordered according to the size of the change in their emissions caused by the maintenance. For the 47 vehicles with reduced emissions:

oxygen sensors repairs occurred in 16 cases,
catalyst repairs occurred in 10 cases,
EGR repairs occurred in 8 cases, and
wiring repairs occurred in 4 cases.

The conclusions from this analysis is that NO_X emissions can be reduced by appropriate repair and maintenance.

Table A3.11 Repairs undertaken on vehicles and the change in NO_X emissions resulting

EPA reference code	change in NO_X emissions (g/mile)	Repairs undertaken (verbatim from EPA report)
For vehicles whose NO_X emissions reduced by ≥ 0.1 g/mile		
CDH18	-4.11	replace the air pump
CDH33	-2.65	repair/replace oxygen sensor, new catalyst
EPA3	-1.88	dealer repair - cpi fuel injector
CDH36	-1.15	plugs and wires, replace computer and catalyst
ATL44	-1.1	replace shorted wiring
CDH10	-0.86	replaced the catalyst, reflashed PCM
ATL129	-0.80	replaced catalyst + 2 oxygen sensors
ATL130	-0.79	replace/repair intake air temperature sensor
EPA18	-0.79	replace catalyst
ARB5	-0.72	new MAF sensor, new catalyst
ATL45	-0.66	water in fuel, replaced fuel pump
CDH14	-0.53	replaced solenoid pack and PCM
ATL1	-0.49	rear oxygen sensor, new catalyst, ignition module
ATL83	-0.44	replace/repair catalyst
CDH28	-0.44	replace canister purge valve and monitor
ATL97	-0.39	oxygen sensor and freed EGR pintle
ATL114	-0.34	replace throttle position sensor
ATL128	-0.33	replace/repair oxygen sensor
ATL8	-0.32	front oxygen sensor, EGR tube gasket
CDH24	-0.30	bare and broken wires due to tampering
CDH25	-0.30	EGR solenoid scan and replace
ARB9	-0.29	front oxygen sensor, new catalyst
ATL48	-0.28	new front oxygen sensor (bank 1)
ATL71	-0.25	replace oxygen sensor and catalyst
ATL73	-0.23	idle air control motor
ATL92	-0.22	all 4 oxygen sensors replaced
ATL125	-0.21	replace/repair oxygen sensor
ATL42	-0.21	replace oxygen sensor
ATL47	-0.21	replaced 2 oxygen sensors
EPA11	-0.20	replace front oxygen sensor and thermostat
ATL104	-0.19	replace/repair cam sensor
ATL72	-0.19	EGR repaired
CDH6	-0.19	replace coil and plugs, clear air flow sensor
ATL60	-0.17	replace cam shaft sensor and drive shaft
ATL38	-0.15	replace MAF
CDH2	-0.15	replaced EGR valve
CDH38	-0.15	repair/replace throttle body and reflash computer
ATL107	-0.14	replace EGR valve
EPA17	-0.14	repair/replace EGR vacuum sensor
ATL126	-0.13	repair throttle position sensor wiring

EPA reference code	change in NO_X emissions (g/mile)	Repairs undertaken (verbatim from EPA report)
For vehicles whose NO_X emissions reduced by ≥ 0.1 g/mile (continued)		
CDH9	-0.13	sealed vacuum leak (upper intake manifold)
EPA24	-0.13	replace upper intake manifold
CDH3	-0.12	replace downstream oxygen sensor, repair vacuum leak
ATL108	-0.10	replace EGR sensor
ATL99	-0.10	replaced intake air temperature sensor
EPA2	-0.10	replace combo valve for secondary air
EPA20	-0.10	repair/replace left oxygen sensor
For vehicles whose NO_X emissions increased by ≥ 0.1 g/mile		
EPA16	0.72	replace EGR valve
CDH7	0.47	replace fuel rail (sugar in petrol)
ATL109	0.35	replace EGR solenoid
ATL119	0.24	fix intake air temperature wiring
ATL7	0.13	replaced oil pump
ATL58	0.11	replaced oxygen sensor
ARB12	0.10	spark plugs replaced