Appendix 5
Details of the cost effectiveness calculations

Contents

APPENDIX 5 DETAILS OF THE COST EFFECTIVENESS CALCULATIONS

COST ANALYSIS

Cost of testing

The section on the generic aspects of cost-effectiveness details the components that comprise the overall costs of a testing regime. For the current in-service test regime the estimate by DTLR is that the average cost of testing a vehicle with a TWC is £7.30[1].

Using fleet composition figures, based on vehicle licensing statistics from the DTLR that form an input to the NAEI model, in 1998 the total number of passenger cars and light duty vehicles was 24.44 million. The NAO also estimated the number of tests carried out at garages on cars and light duty vehicles as 23.00 million (Figure 14 of the NAO report). They comment that this is higher than the number of eligible vehicles because some vehicles undergo more than one test before passing. However, the number of vehicles eligible for testing is less than the whole fleet because vehicles less than three years old are exempt from the test. These figures give the rate of testing as 941 tests per thousand vehicles.

If it is assumed that:

- the cost per test remains at £7.30 / test (1997/8 costs),
- the ratio of the number of tests to the number of eligible vehicles remains constant,
- the ratio of the number of eligible vehicles to the total number of gasoline vehicles in the fleet remains constant,
- the number of gasoline vehicles in the fleet is that given by the input data to the national atmospheric emissions inventory model,

then the cost of testing for future years can be simply calculated, see Table 1.

Table 1 Projected fleet numbers (in thousands), and cost of testing gasoline vehicles

	1998	2005	2010	2015
Total number of pass cars & light duty vans	24,440	27,441	29,424	31,091
Number of gasoline vehicles	20,373	20,740	21,957	23,152
Number of tests	19,171	19,517	20,662	21,786
Cost of testing	£139.95M	£142.48M	£150.83M	£159.04M

Finally it should be noted that this cost does not include the additional cost of rectifying faulty vehicles, item 3.2 in the item list of source costs.

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[1] Private communication with DTLR VSE2, August 2001.

Cost of repair

In Chapter 4 it was found, from data that is admittedly a few years old, that around 5% of cars fitted with TWCs failed the emissions component of the annual road worthiness test. In Section 3.6 the frequency of the occurrence of faults was analysed. These data are the basis for calculating the cost of repair.

The cost of repair can range from £0 to several hundreds of pounds. The former is when a vehicle only just fails the emissions test, often on high lambda, i.e. 1.04. For these vehicles the testing garage will often make very minor modifications/adjustments, and retest the vehicle, which then passes. In these cases the testing garage often subsumes the additional cost of the test at no additional cost to the owner. At the other end of the coat of repair range a vehicle might require a new ECU. The cost of this item and the labour required to fit it is estimated to be £700.

Costs for repair were obtained by contacting main dealers and asking the costs of key parts and fitting. Standard medium sized saloon cars were selected, e.g. Vauxhall Vectra and VW Passat, to give a broad "middle of the range" indicative price. These are used to calculate a weighted mean repair cost, as outlined below.

Table 2 Costs of repairing gasoline vehicles, which fail the annual emissions, test

% of failures	Repair	Cost	Weighted cost
20%	minor adjustments or repair,	£0	£0.00
35%	new λ sensor	£150	£52.50
25%	new exhaust system	£250	£62.50
15%	new catalyst	£300	£45.00
5%	new ECU	£700	£35.00
	Average repair bill		**£195**

Given the number of tests, data from Table 1, a 5.0% average failure rate and the average repair bill derived above, the cost of repairing the emission test failures is estimated to be:

Table 3 Projected annual costs of repairing gasoline vehicles which fail the annual emissions test

	1998	2005	2010	2015
Number of tests (1000s)	19,171	19,517	20,662	21,786
Number of vehicles failing test (1000s)	958.55	975.85	1,033.1	1,089.3
Cost of repairing vehicles	£186.92M	£190.29M	£201.45M	£212.41M

These figures are 1.34 times the cost of the testing. (For 100 vehicles tested at a £730 cost, 5% fail and require an average £195 spending to repair them, i.e. £975, which is 1.34 times the cost of the testing.)

EFFECTIVENESS ANALYSIS

For 1997 the actual effectiveness of the current test regime can be estimated from the MoT test data given in the TRL report[2]. For future years what is calculated is the **savings potential** which is the savings to the Atmospheric Emissions Inventory that would be made if all target vehicles were correctly identified and then rectified. Given the imperfect nature of in-service testing, the savings that would be achieved are actually only a fraction of the savings potential. The closeness of this fraction to unity is one measure of the effectiveness of the in-service test.

The "savings potentials" calculated here are the possible reductions in emissions predicted for a **year-on-year basis for the UK fleet operating in the environment of there being an in-service emissions test that is enforced**, i.e. as present. If one considers an alternative scenario of there being no annual in-service test there is the high probability that the majority of excess emitters will not be rectified because their driveability is unaffected, as discussed above, and because the environmental ethos would change. Currently the ethos is that emissions from vehicles **do** significantly affect health and that is why proper maintenance is required and policed during the annual MOT inspection. The abolition of an annual emissions test is likely to seriously undermine this tenet. Consequently, if the annual savings potential, as reported here, is X ktonnes per year, the savings over a five year period would not be 5X ktonnes but 15X ktonnes because of the cumulative effect of an increasing number of unrectified gross polluters. The 15X comprises X in the first year, 2X in the second, 3X in the third, 4X in the fourth and 5X in the 5th. Over 10 years the savings would be 55X rather than the 10X implied by a simple additive yearly saving.

Finally, it is emphasised that the "savings potentials" calculated here are the reductions possible from an in-service test. They are not the possible savings over and above those achieved by the current test.

Emissions savings for 1997/8

In this section the effectiveness of the current in-service emissions test for gasoline vehicles will be estimated. This is distinct from the potential that exists for savings, which is discussed in the following section.

The foundation for the calculation is the TRL study on nearly 2,200 MOT tests for cars fitted with TWCs. Re-analysis of this data enables the emissions performance of the vehicles tested to be ranked. Vehicles can fail the test on:

- high CO concentrations at low idle
- high CO concentrations at high idle
- high HC concentrations at high idle
- λ outside the prescribed limits at high idle.

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[2] An analysis if emissions data from the MOT test, TJ Barlow, RS Bartlett and ICP Simmons, Report to the DETR ref. PR/SE/474/98, Aug 1998.

The analysis of the data by TRL concluded that vehicles failed on one or more of these criteria. The most common were:

high CO at high idle	2.8% of tests, and
λ outside its prescribed limits	2.3% of tests.

Where vehicles failed on high HC or low λ, this was **always** associated with high CO concentrations except for 1 (in 2174) test.

A vehicle whose CO or λ are beyond the limits requires maintenance, and the emission value to become within limits, before it can legally be used again. In this analysis it is assumed that the maintenance of vehicles with high CO emissions does affect their on-the-road emissions performance, but the maintenance of vehicles with high λ does not. It was further assumed that:

- vehicles whose high idle CO concentrations are above 0.3% are rectified such that on retest their CO concentration equals 0.3%, and
- the extent to which the high idle CO concentration is above 0.3% is equal to the excess emissions for the vehicle on-the-road.

This last point requires further discussion. The challenge is to relate real savings caused by changing high idle CO concentrations to the savings that occur for real driving. It was seen in section 3.5 that the ratio of excess emissions with a given deterioration mechanism (e.g. a reduction in catalyst activity) varies according to the drive cycle used.

The JCS study noted that the correlation between CO levels for the high idle short test and for long loaded tests (either the NEDC or MODEM weighted drive cycles) was poor. However, it was also noted that the highest emitters were high emitters for both the unloaded and loaded tests. In Figure 22 of the JCS detailed report 3, the correlation between raw exhaust CO concentrations at 3,000 rev/min and emissions of the MODEM weighted cycle is given. Broadly 7% CO from idle test is equivalent to 120 g/km emission rate over the MODEM weighted cycle. On page 35 of the JCS detailed report 3, the correlation between the CO emissions over the NEDC and the MODEM weighted cycle is given. This gives, 18 gm/km MODEM weighted as being equivalent to 15 g/km for the NEDC, whence 7% CO from idle test is equivalent to 100 g/km emission rate over the NEDC.

Given the generally accepted relationship that a 2.3 g/km limit (directive 98/69/EC Stage A) over the NEDC represents a 30% reduction on the 2.2 g/km limit (directive 94/12/EC) over the ECE+EUDC cycles. On this basis, the CO limit values for directives 91/441/EEC and 94/12/EC over the NEDC would be 4.06 and 3.29 g/km. If a degradation factor of 1.2 is applied (i.e. that appropriate for vehicle that has travelled 80,000 km), this increases the threshold for an excess emitter, when measured over the NEDC, to 4.87 and 3.95 g/km.

A linear relationship is assumed between the high idle CO concentration and CO emissions from the NEDC, with 7% raw exhaust CO concentration at high idle being equivalent to 100g/km for the NEDC. Given this assumption, then the 0.3% MOT pass/fail limit would correspond to 4.29 g/km – a figure intermediate between the "excess emitter threshold" just derived for vehicles complying with directives 91/441/EEC and 94/12/EC.

What the preceding argument has provided is a way of relating excess CO emissions and on-the-road emissions. It has also checked, on the basis of the relationship, how the 0.3% pass fail limit compares to the European standard emissions figures.

On this basis the TRL data gives 4.7% of the vehicle sample as having been above the 0.3% pass/fail limit. The 95.3% of vehicles with "acceptable" emissions contributed 47.4% of the total cumulative CO emissions; i.e. the failing 4.7% produced over half the total emissions.

If all the 4.7% failing vehicles were repaired such that their high idle CO concentrations became 0.3%, then the cumulative emissions of the repaired fleet would be 55.5% of the total cumulative CO emissions. On this basis, the I&M programme would have led to an emissions reduction of 44.5% of the original cumulative CO emissions total.

This is an interesting observation because the JCS study concludes: "if all the high emitters had been repaired the emission benefits would be approximately 50% for CO and 35% for HC"[3]. Further, examination of the key figure on which this is statement is based, the upper quartile of Figure 15 in the JCS report, reveals that even after maintenance a few (5) cars still had CO emission levels of greater than 20 g/km. If these were rectified to produce, say, 5 g/km, the emission benefits would have been around 57%.

Applying an analogous procedure to that used here to the JCS data gives that for their unmaintained state, emissions from vehicles emitting less than 5 g/km CO accounted for 35% of the total CO emissions (from Figure 15 of the JCS Main Report). In addition, from Figure 13 of the same report, it is seen that the 35% of total CO emissions came from around 84% of the vehicles.

Hence overall, the data from the TRL study is totally consistent with the JCS data if it is remembered that the JCS "Total" sample was skewed having a higher than average number of the highest emitters.

In terms of converting these percentage reductions into ktonnes saved: it is assumed that the contribution to the NAEI of CO from mobile sources is that from the "well maintained" proportion of the fleet. This is based on the methodology for the selection of vehicles from which the inventory is computed. For 1998 the emissions from the fraction of the petrol fuelled fleet fitted with TWCs was 1,334 ktonnes (from 1999 NAEI Road Transport Emissions Projections[4]). In this analysis, this corresponds to the 55.5% of the total emissions (the cumulative CO emissions from the repaired fleet). The 44.5% reduction corresponds, therefore, to 1,070 ktonnes.

So far this analysis has focussed on CO because it was failure of this aspect of the test that predominately led to a vehicle being identified as requiring maintenance. It is virtually inevitable that the very same maintenance led to a reduction in hydrocarbons, and possibly NO_X. The question is how much? This was estimated using data from the JCS study. In the

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[3] taken verbatim from page 32 of JCS Main Report on *the inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency*, May 1998

[4] Emissions data in this Appendix on Cost Effectiveness are taken from the 1999 NAEI Road Transport Emissions Projections. This is the most recent data available, and is used in preference to slightly older data given in Appendix 3 of the report.

JCS project emissions over the NEDC were measured before and after maintenance for CO, HC and NO_X.

The data are:

	CO	HC	NO_X
Before maintenance	100%	100%	100%
After maintenance	60.9%	73.9%	95.7%
Savings relative to the maintained fleet for JCS data	64.2%	35.3%	4.5%
Savings relative to the maintained TRL data	44.5%	24.5%	3.1%

It is assumed that the maintenance for the vehicles in the TRL study causes the same pro-rata emissions savings. Consequently, the 44.5% savings of CO, calculated earlier, are accompanied by savings in HC and NO_X as given in the last line of the data above. The figure that is calculated for hydrocarbons generically is assumed to also apply to benzene and 1,3 butadiene.

From the 1999 NAEI road transport emissions projections data the 1998 emissions from gasoline vehicles fitted with catalysts of NO_X and 1,3 butadiene can be obtained directly[4]: For benzene and NMVOCs the situation is more complex because of the contribution to the total inventory of evaporative emissions. These are not affected by rectifying vehicles whose emissions fail the in-service test and therefore these need to be subtracted. Hence the figures given in Table 4 are the emissions inventory for the combustion from petrol fuelled vehicles fitted with catalysts for the four species. From these inventories and the percentage reductions given above the reduction in emissions achieved were calculated. These too are given in Table 4.

Table 4 Emissions inventory and reduction of emissions achieved for 1998

Species	NMVOCs	Benzene	1,3 butadiene	NO_X
1998 inventory for TWC petrol vehicles (k tonnes)[4]	98.7	5.8	1.0	146
Savings for the maintained fleet from TRL data	24.5%	24.5%	24.5%	3.1%
Reduction in emissions achieved (TRL data)	32.0 kt	1.88 kt	0.33 kt	4.68 kt

Emissions savings potentials for 2005, 2010 and 2015

In this section the potential that exists for emissions savings will be calculated. The basic methodology, for each pollutant, is:

1. to select the model's parameters (possibly to fit some data)
2. to select the pass/fail criterion,
3. to compute the fraction of vehicles above and below the emissions pass/fail criterion
4. to compute the fraction of the total emissions from the vehicles above and below the emissions pass/fail criterion
5. to compute a new revised total of emissions if all failing vehicles (those above the threshold) emitted at a lower rate (e.g. the pass/fail level)

6. express the emissions reduction in terms of the percentage increase to the revised total of emissions for rectified vehicles
7. find the NAEI prediction for the selected pollutant for each selected year
8. multiply the NAEI figure by the emission reduction from 6 above, to convert from percentage of a normalised whole to ktonnes/year.

The first four of these steps uses the data from section 3.5.1, where the number of excess emitters in the fleet was calculated. The fraction of the fleet emitting beyond certain thresholds, expressed as a percentage of the total emissions generated by these vehicles is given in Tables 7 and 8.

Step 5 requires setting an emissions level for rectified vehicles. The smallest saving potential would arise if all the "excess emitters" were repaired to emit at the pass/fail limit. More optimistic scenarios would be that they emitted at less than this. By way of a sensitivity analysis, savings potentials were calculated for three scenarios:
1. the failed emitters emit at the pass/fail limit when repaired
2. the failed emitters emit at 83% of the pass/fail limit when repaired
3. the failed emitters emit at 67% of the pass/fail limit when repaired.

The emissions reduction was then expressed in terms of the percentage change of the revised total of emissions for the repaired vehicles, i.e.

$$(\text{Emissions}_{\text{before repair}} - \text{Emissions}_{\text{after repair}}).100 / \text{Emissions}_{\text{after repair}}.$$

The emissions savings potentials for these three scenarios are given in Table 5.

Table 5 Emissions savings potentials, expressed as %

	RV = PFL*	RV = 0.83xPFL*	RV = 0.67xPFL*
NO_X	28.50%	38.10%	48.50%
Hydrocarbons	14.70%	20.20%	26.20%
CO "Total" sample	79.50%	97.40%	119.40%
CO "Random" sample	4.90%	7.30%	9.80%

* RV = repaired value of emissions
* PFL = pass/fail limit.

The forecast NAEI emission figures for the three selected years, taken from the 1999 NAEI road transport emissions projections, are used to express the emissions savings potential in ktonnes. The projections available did not contain a catalyst/non-catalyst breakdown for the emissions from petrol fuelled vehicles. Therefore the most recently available proportion was used. This was data in the Appendix of a slightly older report from NETCEN, by the author involved in computing the contribution of mobile sources to the NAEI for DEFRA[5]. The other "adjustment" that was made to the data was to subtract the emissions from motor cycles from the inventory for petrol fuelled vehicled because these are non-catalyst vehicles outside the scope of the current in-service roadworthiness emissions test. It was assumed that the repaired value of emissions is 67% of the pass/fail limit. The resulting emissions savings potentials are given in Table 6.

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[5] UK Road transport emission projections, T P Murrels, NETCEN, report AEAT-5953 Issue 1, Jan 2000,

Table 6 Emissions savings potentials, expressed as k tonnes

	NAEI emissions inventory projections (k tonnes)			Emissions savings potential ktonnes		
Year	2005	2010	2015	2005	2010	2015
NO_X	170.7	126.2	106.0	82.8	61.2	51.4
NMVOCs	132.0	117.7	110.9	34.6	30.9	29.0
Benzene	6.51	5.53	5.10	1.71	1.45	1.34
1,3 butadiene	1.37	1.06	0.93	0.36	0.28	0.24
CO Total sample	1,708	1,389	1,171	2,039	1,658	1,398
CO Random sample	1,708	1,389	1,171	167	136	115

Cost effectiveness

Given the costs derived earlier, and listed in Table 1, the cost effectiveness based on the savings potentials in Table 6 can be calculated. The results are tabulated in Table 7. Also included are the cost effectiveness of the existing regime, calculated for the savings that were estimated to have been generated in 1997/8 when divided by the in-service programmes costs for that year.

Table 7 Cost effectiveness achieved in 1997/8, and maximum possible for selected future years. All figures in g/£

	Cost effectiveness achieved	Maximum cost effectiveness that might be achieved		
	1997/8	2005	2010	2015
NO_X	31.8	581.2	405.9	323.1
NMVOC	273.7	242.7	204.5	182.6
Benzene	14.5	11.98	9.61	8.41
1,3 butadiene	4.0	2.53	1.84	1.54
CO "Total"	7,503	14,313	10,995	8,792
CO "Random"		1,175	902	722