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Executive Summary

The National Transport Model (NTM) is the Department for Transport's main strategic policy testing and forecasting tool used to forecast traffic levels and the subsequent congestion and emissions impacts on the national road network of Great Britain (GB).

The model currently uses a series of speed emissions curves that were developed a number of years ago and, together with forecasts of traffic levels and vehicle speeds, these are used to predict future quantities of fuel use and road traffic emissions.

The objective of this work was to provide up-dated speed-emission factor curves for NO_x, PM_{10}, fuel consumption and CO_2 that are:

(a) consistent with the latest speed-related equations for each of the detailed vehicle classifications that were published by the Department in June 2009, and

(b) are consistent with the latest fleet composition projections and methods used in the National Atmospheric Emissions Inventory (NAEI)

A set of emission curves has been developed covering each main vehicle class reflecting the composition of the national fleet in the years 2003, 2004, 2010, 2015, 2020, 2025, 2030 and 2035. An additional set of curves has been developed for vehicles in London affected by the introduction of the Low Emission Zone and taking account of the effect of the specific TfL bus and taxi fleets operating in London. All the emissions curves were developed to a common polynomial expression of the form:

$$EF\ [g/km] = (a + b.x + c.x^2 + d.x^3 + e.x^4 + f.x^5 + g.x^6)/x$$

The fleet composition data and assumptions that underpin the emission curves and the method used to develop them are described in this report. The emission curves are designed to be used in conjunction with additional information relating to the fuel mix of vehicles (petrol and diesel cars and LGVs) and the bus/coach split of the PSV class of vehicles on different road types and the bus and taxi fleets operating in London. The use of these additional data with the factors derived from the emission curves are illustrated by means of a number of examples.

Total GB emissions of NO_x, PM_{10}, fuel consumption and CO_2 in 2003 and 2004 by main vehicle type are provided from the NAEI model to effectively "calibrate" the baseline figures from the NTM using the emission curves.

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1 Introduction

The National Transport Model (NTM) is the Department for Transport's main strategic policy testing and forecasting tool used to forecast traffic levels and the subsequent congestion and emissions impacts on the national road network of Great Britain (GB).

The model currently uses a series of speed emissions curves that were developed a number of years ago and, together with forecasts of traffic levels and vehicle speeds, these are used to predict future quantities of fuel use and road traffic emissions.

The objective of this work was to provide up-dated speed-emission factor curves that are consistent with the latest speed-related emission and fuel consumption equations for each of the different vehicle classifications that were published by the Department in June 2009[1]. The curves are also required to be consistent with the latest fleet composition projections and methods used in the National Atmospheric Emissions Inventory (NAEI).

The aim is to develop a series of curves as polynomial functions relating emission factors for the air pollutants NO_x and PM_{10} in grammes per kilometre to average speed for each main vehicle class (petrol cars, diesel cars, petrol LGVs, diesel LGVs, rigid HGVs, articulated HGVs and buses and coaches) that are representative of the GB fleet in the years 2003, 2004, 2010, 2015, 2020, 2025, 2030 and 2035. Thus the curves are to take into account the turnover of the fleet as older, higher emitting vehicles are gradually replaced with lower emitting vehicles manufactured to tighter Euro emission standards. Similar curves are also required for CO_2 based on speed-related equations for fuel consumption (in grammes fuel consumed per kilometre) using the direct relationship between "ultimate" CO_2 emissions and fuel consumption. This relationship is according to the carbon content of petrol and diesel fuels and works on the premise that all carbon present in the fuel will ultimately produce CO_2 in the atmosphere even if a small proportion is initially emitted in other forms (e.g. carbon monoxide (CO) and volatile organic compounds (VOCs)).

The equations are required to be consistent, as far as possible, with the methods and assumptions used in the forthcoming 2008 version of the NAEI. The NAEI produces annual estimates of total UK emissions of air pollutants using the latest speed-related emission factors combined with traffic activity data (vehicle kilometres (vkm) for current years from the DfT traffic census) and fleet composition data. The latter are used to define the vkm travelled by each main vehicle category proportioned between different fuel types, vehicle or engine sizes and Euro classification according to their age. The NAEI uses the same principles to forecast emissions from the future evolution of the fleet according to predictions of future vehicle sales and survival rates, as well as forecasts in vehicle km according to the NTM.

The work also requires national estimates of total CO_2, NO_x and PM_{10} emissions from road transport for the years 2003 and 2004 based on the NAEI for the purpose of calibrating NTM's emission calculations. The requirement was for these to be provided at GB level (rather than UK) and to be split between cars and LGVs (vans), HGVs and buses and coaches (PSVs), further split by fuel type (petrol and diesel).

The speed-emission factor curves for each main vehicle class and year and the GB emissions for 2003 and 2004 have been provided to ITEA Division of DfT in spreadsheet form. This report describes the derivation and use of the factors.

[1] http://www.dft.gov.uk/pgr/roads/environment/emissions/

2 Approach Used to Derive Emission Curves

The general approach adopted was to:

- take the speed-emission factor curves for the many detailed categories of vehicles published by DfT in June 2009
- scale them according to year-dependent and vehicle-specific scaling factors that take into account fuel quality effects and extent of emission degradation, and
- weight the scaled coefficients defining the shape and magnitude of the curves according to the composition of the national fleet by Euro standard and vehicle size for each main vehicle type and for each year.

The desired result was a single curve, as a fleet-weighted polynomial emission factor-speed function, for each main vehicle category and year for each pollutant. This section describes the key input data sets and assumptions used to develop the emission curves.

2.1 Source of Raw Speed - Emission Factor Curves

The basic speed-emission factor curves for NO_x, PM and fuel consumption (FC) were taken from the equations recently published by DfT following the work undertaken by TRL. TRL hold a large database of emission factors measured over a range of drive cycles in vehicle emission test programmes in Europe and the UK, including the large EU ARTEMIS Programme and a number of research programmes funded by DfT. TRL grouped the raw test data into a number of vehicle categories, plotted them against average speed of the test cycle and fitted to a common polynomial expression of the form:

$$EF\ [g/km] = k*(a + b.x + c.x^2 + d.x^3 + e.x^4 + f.x^5 + g.x^6)/x \qquad (1)$$

where a, b, c, d, e, f, g and k are coefficients and x is speed in kph. The factors are given for a range of different vehicle classes, sizes and fuel types and for each legislative Euro standard from pre-Euro 1 up to Euro 6/VI. The factors given are normalised to 50,000km accumulated mileage.

Details of the raw test data, including their source, the process used to analyse them and develop the polynomial speed – emission factor curves are given in the TRL project report to DfT by Boulter et al (2009)[2]. As vehicles meeting Euro 5/V and 6/VI standards have not yet entered service, TRL made assumptions about the emission performance of these vehicles relative to Euro 4/IV on the basis of limit values given in relevant EU Directives on emission taking into account durability requirements.

An example of the basic speed-emission factor curves for NO_x for a medium-sized petrol car is shown in Table 1.

2.2 Scaling Factors for Emission Degradation and Fuel Quality Effects

The emission factors calculated from these functions are normalised to an accumulated mileage of 50,000 km and to a specific quality of fuel. For some vehicle categories, TRL analysed how emission factors change with a vehicle's accumulated mileage and provided a set of scaling factors to apply to the basic factor calculated from the speed – emission curve assuming a linear relationship with mileage. In most cases, emissions deteriorate with increasing mileage, but in some cases emissions appear to improve. The change in accumulated mileage can be associated with vehicle

[2] http://www.dft.gov.uk/pgr/roads/environment/emissions/report3.pdf

Table 1: Basic speed-emission factor coefficients for NO_x emissions from a medium-sized petrol car (taken from Boulter et al, 2009). The coefficients are used to calculate an emission factor at speed x from an equation of the form EF [g/km] = $k*(a + b.x + c.x^2 + d.x^3 + e.x^4 + f.x^5 + g.x^6)/x$

				Coefficients								Valid speed range	
Vehicle type	Fuel type	Engine capacity (cc) or weight limit (tonnes)	Emission standard	a	b	c	d	e	f	g	k	Minimum (km/h)	Maximum (km/h)
Car <2.5 t	Petrol	1400-2000 cc	Pre-Euro 1	5.8816	0.6836	0.0139	0	0	0	0	1	5	140
Car <2.5 t	Petrol	1400-2000 cc	Euro 1	2.3658376	0.1992612	0.0006471	3.221E-06	0	0	0	1	5	120
Car <2.5 t	Petrol	1400-2000 cc	Euro 2	1.0952615	0.1201239	0.0006135	1.167E-06	8.779E-09	0	0	1	5	140
Car <2.5 t	Petrol	1400-2000 cc	Euro 3	0.4370444	0.0613598	8.022E-05	8.834E-08	0	0	0	1	5	140
Car <2.5 t	Petrol	1400-2000 cc	Euro 4	0.5169139	0.0345016	5.493E-05	4.085E-07	0	0	0	1	5	120
Car <2.5 t	Petrol	1400-2000 cc	Euro 5	0.5169139	0.0345016	5.493E-05	4.085E-07	0	0	0	0.594	5	120
Car <2.5 t	Petrol	1400-2000 cc	Euro 6	0.5169139	0.0345016	5.493E-05	4.085E-07	0	0	0	0.594	5	120

age, so this enabled TRL to develop year-dependent scaling factors to take into account emission degradation with mileage and the change in mileage with age. The quality of fuel has been improving over the years since some of the emission measurements were first made as a consequence of more stringent fuel quality directives and the improvement in fuel quality (e.g. the sulphur content) can affect emission factors. TRL provided scaling factors to take into account the impact of changes in fuel quality on emissions and using the uptake rates of improved fuels in the UK, it was possible to convert these into year-dependent fuel scaling factors.

In summary, the emission factors developed from the basic speed-emission curves are designed to be adjusted by the application of a year-dependent scaling factor that takes into account the effects of changing fuel quality and the degradation of emissions with a vehicle's accumulated mileage.

2.3 Fuel Consumption Factors for HGVs

The fleet-weighted speed-emission curves for fuel consumption, NO_x and PM_{10} for all vehicle types were calculated from these raw speed-emission curves in the same way, but for HGVs an additional source of data was used in the development of fuel consumption (and CO_2) curves.

DfT's Continuous Survey of Road Goods Transport is published each year, giving amongst a range of statistics, the average miles per gallon fuel efficiency of different sizes of rigid and artic HGVs. The information is reported for all years from 1989 to 2007 in Table 5.1 of DfT's Transport Statistics Bulletin, "*Road Freight Statistics: 2007*" (DfT, 2008)[3]. These data have an advantage over the TRL speed functions as a source of fuel consumption factors for HGVs in the UK as they are based on a larger sample of actual HGV operations obtained through surveys of haulage firms, whereas the fuel consumption factors derived from the TRL database are based on measurements from tests on just a few individual vehicles. In accordance with the methodology adopted for the NAEI, use was made of both sources of fuel consumption data for HGVs: the CSRGT data which gives a single, average fuel consumption factor covering a large and representative sample of UK operations, but no indication of how this varies with speed; and the TRL speed curves which are based on a much smaller, less representative sample of vehicles but give a wide indication of how fuel consumption varies with speed.

The method used for combining these two different data sets in the compilation of the fleet-averaged HGV fuel consumption factors in this study is described in Section 3.2.

2.4 Fleet Composition Data

The NTM requires a single speed-emission curve that reflects the speed-dependence of the average emissions or fuel consumption factor for each main vehicle category weighted by the composition of the vehicle fleet in each year. To do this, the detailed speed-emission curves described above must be weighted with fleet composition data that express the fraction of vehicles of different sizes or weights in the fleet and proportion of vehicle kilometres travelled by each Euro standard.

The NAEI has recently updated the fleet composition data and projections for each main vehicle class to align with the vehicle categories used in the latest DfT/TRL speed-emission factor curves. These have been used by the NAEI to update the UK emission projections of NO_x, PM and other air pollutants and the corresponding fleet data have been made available to Defra, their modelling contractors and other divisions of DfT.

The updated fleet composition projections are based on updated assumptions about vehicle survival rates, new vehicle sales and the mix of petrol and diesel in new car sales. Collectively, these assumptions define the turnover in the vehicle fleet. In deriving the fleet composition, the following assumptions were made:

[3] http://www.dft.gov.uk/pgr/statistics/datatablespublications/freight/goodsbyroad/roadfreightstatistics2008

- Revised survival rate and sales projections after a recent NAEI study (2009) on reviewing the vehicle turnover assumptions used in the NAEI road transport emission projections. This was based on a detailed examination by the NAEI of DfT vehicle licensing data showing historic trends in new vehicle sales and survival rates from year-of-first registration data. No changes were made to the description of how the annual mileage of vehicles change with vehicle age, as no new mileage with age data were available. However, the composition data calculated for the fleet are still in terms of proportions of km by each Euro standard taking into account changes in mileage as well as lifetime of vehicles rather than in terms of proportions of vehicle population.

- Revised diesel penetration rate in the car fleet based on more recent estimates from DfT (March 2009). It is now assumed that diesel car sales rise to 39% of all car sales by 2010, then 43% by 2020 and stay constant thereafter. This is a slower penetration rate than previously assumed for which the assumptions were 41% by 2010, 47% by 2020 and 50% by 2025.

- Revised catalytic failure assumptions (as agreed with DfT) based on new evidence on fitting of replacement catalysts and taking into account of Regulations Controlling Sale and Installation of Replacement Catalytic Converters and Particle Filters for Light Vehicles for Euro 3 (or above) LDVs after June 2009. Failure rates of 5% per annum are assumed for all petrol car and LGV Euro standards, but different repair rates are assumed for each Euro standard before and after 2009. When a petrol car/LGV fails, emission factors for pre-Euro 1 vehicles are assumed. Failure of systems on Euro 5/6 diesel cars and LGVs for controlling NO_x and PM are also assumed. For PM, failure rates apply to both Euro 5 and 6 diesel cars and LGVs (due to failure of catalyst based PM filters) and when a vehicle fails, PM emission factors for Euro 4 vehicles are assumed. For NO_x, failure rates apply only to Euro 6 diesel cars and LGVs (due to failure of SCR system) and when a vehicle fails, NO_x emission factors for Euro 5 are assumed.

- The mix of petrol and diesel cars on the road is derived from the fleet turnover and vehicle sales assumptions, and the changes in annual mileage with vehicle age. However, data from DfT (originated from the National Travel Survey) show that diesel cars do 60% more mileage than petrol cars, so this would vary the amount of diesel vkm on GB roads relative to petrol cars based on the diesel/petrol car mix in the fleet. A different petrol car/diesel car mix is assumed on different road types (previously assumed the split was the same everywhere) on the basis that the additional mileage by diesel cars is done mainly on motorways and rural roads. Information from this dataset on variation in car annual mileage by engine sizes has also been used.

- The composition of the fleet by vehicle or engine size is based on vehicle licensing records and the current composition is assumed to remain constant in future years

Table 2 shows the UK fleet composition in terms of the proportion of vkm by each Euro standard. This table provides data up to 2025 which is the year the current NAEI emission projections extend to. A requirement of this work was to provide emission curves up to 2035. However, as the current fleet projections are based on near-term technologies and legislative standards (up to 2015), there will be little difference in the fleet-weightings used for years between 2025 and 2035. Emission curves extending to 2035 were provided using fleet composition derived by linearly extrapolating the trend in new vehicle sales beyond 2025 and assuming the same vehicle survival rates. Although not shown in Table 2, the fleet composition from 2025 and 2035 can be provided.

The fleet projections and emission curves are based on conventional vehicles, fuels and technologies meeting emission standards up to Euro 6/VI which will come into effect in 2015/2016. Although the penetration of alternative fuels and vehicle technologies can be expected on the time-horizon of this study (e.g. hybrids and electric vehicles), the penetration of these vehicles were not included in the fleet composition data and emission curves generated. There is currently insufficient data to indicate the likely uptake of these new technologies and these are not included in the latest “Business as Usual” assumptions underlying the NAEI emission projections provided to Defra.

Table 3 provides a further breakdown in the petrol car, diesel car and diesel LGV fleet in terms of the

Table 2: UK Fleet Composition Projections - Proportion of VKM by Euro Standard

		2003	2004	2010	2015	2020	2025
Petrol cars	Pre-Euro 1	0.105	0.072	0.003	-	-	-
	Euro 1	0.193	0.165	0.028	0.002	-	-
	Euro 2	0.320	0.295	0.138	0.021	0.001	-
	Euro 3	0.254	0.257	0.160	0.052	0.005	-
	Euro 4	0.128	0.211	0.615	0.366	0.123	0.015
	Euro 5	-	-	0.056	0.469	0.288	0.107
	Euro 6	-	-	-	0.090	0.583	0.879
	ALL	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Diesel cars	Pre-Euro 1	0.040	0.025	0.001	-	-	-
	Euro 1	0.206	0.154	0.014	0.001	-	-
	Euro 2	0.247	0.198	0.050	0.006	0.000	-
	Euro 3	0.454	0.537	0.258	0.089	0.011	0.000
	Euro 3 with DPF*	0.054	0.086	0.048	0.018	0.002	0.000
	Euro 4	-	-	0.441	0.218	0.079	0.010
	Euro 4 with DPF	-	-	0.110	0.054	0.020	0.002
	Euro 5	-	-	0.077	0.512	0.278	0.098
	Euro 6	-	-	-	0.102	0.610	0.889
	ALL	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Petrol LGV	Pre-Euro 1	0.365	0.264	0.013	-	-	-
	Euro 1	0.114	0.105	0.021	0.002	-	-
	Euro 2	0.305	0.285	0.125	0.023	0.002	-
	Euro 3	0.216	0.346	0.273	0.113	0.019	0.001
	Euro 4	-	-	0.568	0.361	0.150	0.027
	Euro 5	-	-	-	0.501	0.313	0.133
	Euro 6	-	-	-	-	0.516	0.839
	ALL	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Diesel LGVs	Pre-Euro 1	0.106	0.075	0.006	-	-	-
	Euro 1	0.160	0.132	0.022	0.002	-	-
	Euro 2	0.430	0.359	0.125	0.023	0.002	-
	Euro 3	0.305	0.435	0.275	0.113	0.019	0.001
	Euro 4	-	-	0.572	0.361	0.150	0.027
	Euro 5	-	-	-	0.501	0.313	0.133
	Euro 6	-	-	-	-	0.516	0.839
	ALL	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Rigid HGV	Pre-Euro I	0.085	0.053	-	-	-	-
	Euro I	0.129	0.099	0.003	-	-	-
	Euro II	0.522	0.471	0.139	0.009	-	-
	Euro III	0.263	0.377	0.391	0.125	0.008	-
	Euro IV	-	-	0.196	0.114	0.027	-
	Euro V	-	-	0.271	0.444	0.203	0.032
	Euro VI	-	-	-	0.307	0.761	0.968
	ALL	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

		2003	2004	2010	2015	2020	2025
Artic HGV	Pre-Euro I	0.027	0.014	-	-	-	-
	Euro I	0.090	0.060	0.001	-	-	-
	Euro II	0.549	0.457	0.077	0.003	-	-
	Euro III	0.334	0.468	0.410	0.092	0.003	-
	Euro IV	-	-	0.235	0.105	0.014	-
	Euro V	-	-	0.277	0.468	0.150	0.014
	Euro VI	-	-	-	0.332	0.833	0.986
	ALL	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Buses & coaches	Pre-Euro I	0.102	0.076	0.009	-	-	-
(outside London)	Euro I	0.107	0.082	0.016	0.003	-	-
	Euro II	0.504	0.447	0.151	0.042	0.006	-
	Euro III	0.287	0.394	0.391	0.158	0.045	0.007
	Euro IV	-	-	0.191	0.131	0.039	0.012
	Euro V	-	-	0.241	0.406	0.229	0.064
	Euro VI	-	-	-	0.260	0.681	0.916
	ALL	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

* A DPF is a diesel particulate filter equipped to diesel vehicles to reduce emissions of PM_{10}.

Table 3 Proportion of vkm by vehicles with catalyst systems in a failed state or a functioning state.

			2003	2004	2010	2015	2020	2025
Petrol cars	Pre-Euro 1		0.105	0.072	0.003	0.000	0.000	0.000
	Euro 1	OK	0.160	0.137	0.023	0.001	0.000	0.000
		FAIL	0.032	0.028	0.005	0.000	0.000	0.000
	Euro 2	OK	0.270	0.248	0.115	0.017	0.001	0.000
		FAIL	0.049	0.047	0.024	0.004	0.000	0.000
	Euro 3	OK	0.237	0.235	0.158	0.052	0.005	0.000
		FAIL	0.017	0.022	0.002	0.001	0.000	0.000
	Euro 4	OK	0.123	0.200	0.607	0.362	0.121	0.014
		FAIL	0.005	0.011	0.007	0.005	0.002	0.000
	Euro 5	OK	0.000	0.000	0.055	0.463	0.285	0.105
		FAIL	0.000	0.000	0.000	0.006	0.004	0.001
	Euro 6	OK	0.000	0.000	0.000	0.089	0.576	0.869
		FAIL	0.000	0.000	0.000	0.001	0.006	0.010
		ALL	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Diesel cars	Pre-Euro 1		0.040	0.025	0.001	-	-	-
	Euro 1		0.206	0.154	0.014	0.001	-	-
	Euro 2		0.247	0.198	0.050	0.006	0.000	-
	Euro 3		0.507	0.623	0.306	0.108	0.014	0.001
	Euro 4		-	-	0.552	0.272	0.098	0.012
	Euro 5	OK	-	-	0.077	0.506	0.275	0.097
		FAIL	-	-	-	0.006	0.003	0.001
	Euro 6	OK	-	-	-	0.101	0.603	0.879
		FAIL	-	-	-	0.001	0.007	0.010
	ALL		**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

			2003	2004	2010	2015	2020	2025
Diesel LGVs	Pre-Euro 1		0.106	0.075	0.006	-	-	-
	Euro 1		0.160	0.132	0.022	0.002	-	-
	Euro 2		0.430	0.359	0.125	0.023	0.002	-
	Euro 3		0.305	0.435	0.275	0.113	0.019	0.001
	Euro 4		-	-	0.572	0.361	0.150	0.027
	Euro 5	OK	-	-	-	0.496	0.309	0.131
		FAIL	-	-	-	0.005	0.004	0.002
	Euro 6	OK	-	-	-	-	0.511	0.830
		FAIL	-	-	-	-	0.006	0.010
	ALL		**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

proportion of vkm by vehicles with catalyst systems in a failed state or a functioning state, again as far as 2025.

Table 4 shows the composition of each main vehicle fleet according to engine size or vehicle weight. The engine size and vehicle weight categories are to align with the size categories used in the raw speed-emission factor curves. It is assumed that these remain unchanged in future years.

Table 4: Proportion of vehicles by engine size or vehicle weight used in deriving speed-emission curves for each main vehicle type from the raw emission functions provided by DFT/TRL for detailed vehicle size categories

Petrol car <2.5t	<1400cc	38.3%
	1400-2000cc	47.7%
	>2000cc	14.1%
Diesel car <2.5t	<1400cc	5.2%
	1400-2000cc	63.6%
	>2000cc	31.1%
LGVs	N1 (I)	6%
	N1 (II)	26%
	N1 (III)	68%
Rigid HGVs	3.5-7.5 t	47%
	7.5-12 t	3%
	12-14 t	3%
	14-20 t	22%
	20-26 t	7%
	26-28 t	5%
	28-32 t	11%
	>32 t	1%
Artic HGV	14-20 t	0%
	20-28 t	7%
	28-34 t	3%
	34-40 t	82%
	40-50 t	7%
Bus	<15 t	31%
	15-18 t	69%

Coach	15-18 t	50%
	>18 t	50%

The fleet composition figures in Table 2 refer to the whole of GB. However, consideration was given to the LGV, HGV and bus fleets operating in London which are expected to be different to the national fleet because of implementation of the London Low Emission Zone (LEZ). This scheme restricts entry into the LEZ by vehicles below a certain Euro standard and is being implemented in stages. The minimum standards are: Euro III for HGVs and buses in stages from 2008 (Phase 1 & 2); Euro 3 for LGVs from October 2010 (Phase 3); Euro IV for HGVs and buses from January 2012 (Phase 4). A different set of fleet composition data was used to develop fleet-weighted emission curves for these vehicles in London reflecting the impact of the LEZ and other specific policies and measures introduced by Transport for London (TfL) to upgrade the London bus and taxi fleet. TfL buses are distinct from other buses operating in London and those entering London from the rest of the UK. Emissions from taxis (black cabs) are treated explicitly for London using fleet composition data from TfL based on the London Taxi Emission Strategy and are important because they make up a significant proportion of car km in London (Section 4.2). Taxis are not considered in other cities due to lack of information on the fleets.

Table 5 shows the fleet composition for LGVs, HGVs, buses and taxis in London in terms of the proportion of vkm by each Euro standard from 2010 to 2025. 2010 is the first model year after the LEZ becomes implemented and before this year the GB fleet data are used for London. The fleet composition for cars in London is assumed to be the same as the rest of GB. The fleet composition for buses and coaches are composite of the TfL bus fleet and the fleet of other buses and coaches operating in London and entering London from the rest of the UK based on an estimate that 75% of all bus km in London are by TfL buses, the rest are non-TfL buses.

Table 5: London Fleet Composition Projections - Proportion of VKM by Euro Standard

		2010	**2015**	**2020**	**2025**
Petrol LGVs	Pre-Euro 1	0.010	-	-	-
	Euro 1	0.017	-	-	-
	Euro 2	0.099	-	-	-
	Euro 3	0.284	0.115	0.019	0.001
	Euro 4	0.591	0.370	0.150	0.027
	Euro 5	-	0.514	0.314	0.133
	Euro 6	-	-	0.517	0.839
	ALL	**1.000**	**1.000**	**1.000**	**1.000**
Diesel LGVs	Pre-Euro 1	0.005	-	-	-
	Euro 1	0.017	-	-	-
	Euro 2	0.099	-	-	-
	Euro 3	0.285	0.115	0.019	0.001
	Euro 4	0.594	0.370	0.150	0.027
	Euro 5	-	0.514	0.314	0.133
	Euro 6	-	-	0.517	0.839
	ALL	**1.000**	**1.000**	**1.000**	**1.000**
Rigid HGV	Pre-Euro I	-	-	-	-
	Euro I	-	-	-	-
	Euro II	-	-	-	-
	Euro III	0.455	-	-	-
	Euro IV	0.229	0.132	0.027	-
	Euro V	0.316	0.513	0.205	0.032
	Euro VI	-	0.355	0.768	0.968
	ALL	**1.000**	**1.000**	**1.000**	**1.000**

		2010	2015	2020	2025
Artic HGV	Pre-Euro I	-	-	-	-
	Euro I	-	-	-	-
	Euro II	-	-	-	-
	Euro III	0.444	-	-	-
	Euro IV	0.255	0.116	0.014	-
	Euro V	0.301	0.517	0.151	0.014
	Euro VI	-	0.367	0.835	0.986
	ALL	**1.000**	**1.000**	**1.000**	**1.000**
Buses & coaches	Pre-Euro I	-	-	-	-
	Euro I	-	-	-	-
	Euro II	-	-	-	-
	Euro II + trap	0.152	-	-	-
	Euro III	0.119	-	-	-
	Euro III + trap	0.414	0.251	-	-
	Euro IV	0.227	0.278	0.183	0.003
	Euro V	0.073	0.127	0.060	0.016
	Euro VI	-	0.082	0.179	0.231
	Hybrid (relative to Euro V)	0.014	0.072	0.072	0.072
	Hybrid (relative to Euro VI)	-	0.188	0.504	0.633
	Hydrogen Fuel Cell	0.001	0.002	0.002	0.045
	ALL	**1.000**	**1.000**	**1.000**	**1.000**
Taxi	Pre-Euro 1	-	-	-	-
	Euro 1	-	-	-	-
	Euro 2	-	-	-	-
	Euro 3	0.790	0.540	0.290	-
	Euro 4	0.200	0.250	0.250	-
	Euro 5	-	0.100	0.200	-
	Euro 3	0.010	0.010	0.010	-
	Hybrid (relative to Euro 5)	-	0.100	0.100	0.100
	Hybrid (relative to Euro 6)	-	-	0.150	0.900
	ALL	**1.000**	**1.000**	**1.000**	**1.000**

3 Generation of Emission Curves

3.1 Pollutant Emission Curves

Because the emission curves for all detailed vehicle categories were provided in the same functional form, as polynomial expressions to the v^6 power, it was straightforward to develop a single curve in the same form representing the average emission factor for all vehicles in the main vehicle category in a given year by weighting all the common coefficients according to the composition of the vehicle fleet in that year.

This is best illustrated for petrol cars, by way of example.

For year y, the emission curve for each medium-sized petrol car Euro standard is given by:

$$EF_{ye} = D_{ye}.S_{ye}.k_e.(a_e + b_e.x + c_e.x^2 + d_e.x^3 + e_e.x^4 + f_e.x^5 + g_e.x^6)/x \quad (2)$$

where:

D_{ye} = scaling factor for degradation effects for Euro standard e in year y
S_{ye} = scaling factor for fuel quality effects for Euro standard e in year y
a_e - g_e and k_e are the speed-emission factor coefficients for Euro standard e, as given in Table 1.

Equations like this can then be aggregated to a single expression weighted by the proportion of vehicle kilometres done by each Euro standard as given in Table 2, via:

$$EF_y = R_{yo}.EF_{yo} + R_{y1}.EF_{y1} + R_{y2}.EF_{y2} + R_{y3}.EF_{y3} + R_{y4}.EF_{y4} + R_{y5}.EF_{y5} + R_{y6}.EF_{y6} \quad (3)$$

where

R_{yo} is the fraction of petrol car km by pre-Euro 1 vehicles in year y
R_{y1} is the fraction of petrol car km by Euro 1 vehicles in year y
R_{y2} is the fraction of petrol car km by Euro 2 vehicles in year y, and so on, as given in Tables 2 and 3.

and

EF_{y1}, EF_{y2} …. etc are the emission factors for Euro 1, Euro 2 …. etc medium-sized petrol car in year y, given by Equation (2), leading to the single expression:

$$EF_y = (A_y + B_y.x + C_y.x^2 + D_y.x^3 + E_y.x^4 + F_y.x^5 + G_y.x^6)/x \quad (4)$$

where:

$$A_y = R_{y0}.D_{y0}.S_{y0}.k_o.a_o + R_{y1}.D_{y1}.S_{y1}.k_1.a_1 + R_{y2}.D_{y2}.S_{y2}.k_2.a_2 + R_{y3}.D_{y3}.S_{y3}.k_3.a_3 + R_{y4}.D_{y4}.S_{y4}.k_4.a_4 + R_{y5}.D_{y5}.S_{y5}.k_5.a_5 + R_{y6}.D_{y6}.S_{y6}.k_6.a_6 \quad (5)$$

$$B_y = R_{y0}.D_{y0}.S_{y0}.k_o.b_o + R_{y1}.D_{y1}.S_{y1}.k_1.b_1 + R_{y2}.D_{y2}.S_{y2}.k_2.b_2 + R_{y3}.D_{y3}.S_{y3}.k_3.b_3 + R_{y4}.D_{y4}.S_{y4}.k_4.b_4 + R_{y5}.D_{y5}.S_{y5}.k_5.b_5 + R_{y6}.D_{y6}.S_{y6}.k_6.b_6 \quad (6)$$

$$C_y = R_{y0}.D_{y0}.S_{y0}.k_o.c_o + R_{y1}.D_{y1}.S_{y1}.k_1.c_1 + R_{y2}.D_{y2}.S_{y2}.k_2.c_2 + R_{y3}.D_{y3}.S_{y3}.k_3.c_3 + R_{y4}.D_{y4}.S_{y4}.k_4.c_4 + R_{y5}.D_{y5}.S_{y5}.k_5.c_5 + R_{y6}.D_{y6}.S_{y6}.k_6.c_6 \quad (7)$$

and so on.

In other words, the coefficients A-G are weightings of the individual coefficients a-g for the different Euro standards (from pre-Euro 1 (denoted as Euro 0) to Euro 6) according to the fractions in the fleet in year y.

Equation (4) and the coefficient A_y-G_y denote the expression in this example of the fleet-weighted emission curve of a medium-sized petrol car in year y. A further weighting is required to derive a single expression for all petrol cars in years according to the mix of small, medium and large petrol cars in the fleet, given in Table 4 (<1400c, 1400-2000cc, >2000cc). Thus the coefficients A_y are calculated for small, medium and large petrol cars and weighted according to:

$$A_{y,\text{ petrol cars}} = 0.383.A_{y,\text{small}} + 0.477.A_{y,\text{medium}} + 0.141.A_{y,\text{large}} \quad (8)$$

and similarly for the coefficient B_y to G_y.

The coefficients $A_{y,\text{ petrol cars}}$ – $G_{y,\text{ petrol cars}}$ calculated in this way are the coefficients "a" - "g" provided to DfT in spreadsheet form for each year y.

Coefficients were calculated in the same way for all other main vehicle types, pollutants and years.

An example of the speed-emission curve coefficients for NO_x emissions from petrol cars and diesel cars for the years 2003, 2004, 2010, 2015, 2020, 2025, 2030 and 2035 is given in Table 6. Use of these coefficients in an equation

$$EF = (a + bx + c.x^2 + d.x^3 + e.x^4 + f.x^5 + g.x^6)/x \quad (9)$$

will yield the fleet-average NO_x emission factor in g/km for petrol and diesel cars in each year at speed x, where x is in kilometres per hour.

A different set of emission curves was developed for LGVs, HGVs and buses in London to take account of the effect of the London LEZ. The scheme does not apply to cars, so the car fleet in London is assumed to be the same as the national fleet and hence the emission curves developed for cars in GB are assumed to apply to cars in London.

3.2 Fuel Consumption Emission Curves

Speed coefficients for fuel consumption were also developed in the same way, but for HGVs an additional step was taken to bring the speed-related fuel consumption curves in line with the mpg fuel efficiency rates published in the CSRGT, as mentioned in Section 2.3. This involved a normalisation process described as follows.

Initially, speed-related functions for rigid and artic HGV fuel consumption were derived in the same way as described above for other pollutants and vehicle types. These curves were then used to calculate the average fuel consumption factors in litre/100 km at typical HGV speeds on urban, rural and motorway roads. An overall, average fuel consumption factor for rigid and artic HGVs was then derived by weighting the road-type factors according to the proportion of vkm done on urban, rural and motorway roads using data from DfT. This led to an average fuel consumption factor of 19.89 litre/100km and 34.16 litre/100km for rigid and artic HGVs in 2004, respectively.

These values come from factors derived from research measurements based on a few vehicles tested under different drive cycles. They compare with average fuel consumption factors derived from figures given in Table 5.1 of the CSRGT (based on a survey of hauliers) of 26.97 litre/100km for rigids and 35.13 litre/100km for artic HGVs in 2004. The CSRGT values are derived by weighting those given for individual sizes of HGVs by the proportion of vkm travelled by each size class. The ratio of the fuel consumption from the CSRGT to fuel consumption from the measurement test sample is therefore 26.97/19.89 = 1.351 for rigid HGVs and 35.13/34.16 = 1.025 for artic HGVs; in other words the fuel consumption rates of the sample of HGVs tested in order to derive the speed curves are below the GB average based on haulage surveys. The discrepancy between the research-based factors and the CSRGT-derived factors may reflect 'real-world' effects, such as the actual, and variable, state of loading of HGVs used in UK haulage operations (all the research-based factors are based on a 50% loading condition) and the types of real journeys undertaken in the UK. The discrepancy may also reflect the HGV fleet in the UK (e.g. size, type and configuration) being at variance to the small sample of HGVs that would have been tested for the research-based factors. For all these reasons, the CSRGT-based factors are considered more representative of HGV fleet and operations occurring in the UK than the research-based factors and therefore take precedence.

To bring the speed-related functions for fuel consumption by HGVs in line with the figures in CSRGT all the speed-coefficients were scaled up by a factor of 1.351 for rigid HGVs and 1.025 for artic HGVs. These adjustment factors refer to HGVs in 2004, but were assumed to be applicable to all future years and thus to bring consistency with 2004 factors and avoid sudden step changes the speed-coefficients derived for fuel consumption by HGVs in years 2010-2035 were scaled by the same amount.

Such a reconciliation of two very different sources of data on fuel consumption is currently unique to HGVs and presently these are the only vehicle types where the raw speed-related coefficients, weighted by the fleet composition, have been adjusted.

Whereas the LEZ will have a major effect on the fleet-averaged factors for NO_x and PM_{10} emissions from LGVs, HGVs and buses in London, and hence an alternative set of factors is provided, the impact of the scheme on fuel consumption factors will be less significant. In terms of fuel consumption, the main differences between the fleet in London and the rest of GB will be in the factors for buses and taxis reflecting the series of measures and alternative fuels and technologies being introduced by TfL. Hence, only for these vehicles are separate London-specific emission curves provided for fuel consumption and CO_2 emissions. For cars, LGVs and HGVs, the speed-emission curves developed for the GB fleet should be assumed to apply to these vehicles in London.

Table 7 show the fuel consumption-speed coefficients derived this way for rigid and artic HGVs. These are the coefficients provided in spreadsheets to DfT, yielding fuel consumption in units of litre/100km.

3.3 CO_2 Emission Curves

Curves for ‘ultimate’ CO_2 emissions were derived directly from the fuel consumption by converting the units from litre/100km to g fuel/km and applying a simple conversion factor based on the carbon content of petrol and diesel fuels. The fuel carbon contents used in the Greenhouse Gas Inventory are provided by personal communication with the UK Petroleum Industry Association and remain constant in all years at 85.5% for petrol and 86.3% for diesel (UKPIA, 2004). These figures refer to the percentage carbon content by mass, in other words 100 grammes diesel comprises 86.3 grammes carbon.

The mass density of fuel is 1.199 litre per kg fuel for diesel and 1.361 litre per kg fuel for petrol (BERR, 2008). From this it follows that the factors for converting fuel consumption in litres/100km to CO_2 emissions in gCO_2/km are:

Petrol: 23.03
Diesel: 26.39

Table 6: Speed-emission factor coefficients for NO_x emissions from the fleet of petrol and diesel cars in years 2003-2035. These coefficients are to be used in an equation of the form $EF = (a + bx + c.x^2 + d.x^3 + e.x^4 + f.x^5 + g.x^6)/x$ where x is average speed in kph. Coefficients for other vehicle types and for PM_{10}, fuel consumption and CO_2 were provided in spreadsheet tables to DfT.

Region	Pollutant	Year	Vehicle type	Fuel type	Unit	Function	Coefficients						
						Type	a	b	c	d	e	f	g
GB	NOx	2003	Car	Petrol	g/km	Polynomial	3.617189	0.195257	0.00397	6.42E-08	3.16E-08	-4E-11	3.08E-13
		2004	Car	Petrol	g/km	Polynomial	3.226565	0.171465	0.003422	5.19E-08	2.82E-08	-3.7E-11	2.76E-13
		2010	Car	Petrol	g/km	Polynomial	1.4367	0.055602	0.000879	2.25E-07	7.57E-09	-1.5E-11	1.07E-13
		2015	Car	Petrol	g/km	Polynomial	0.992683	0.027959	0.000355	1.59E-07	2.78E-09	-7.3E-12	3.49E-14
		2020	Car	Petrol	g/km	Polynomial	0.841487	0.022184	0.000273	1.69E-07	1.34E-09	-8.8E-13	3.56E-15
		2025	Car	Petrol	g/km	Polynomial	0.809827	0.0214	0.000268	1.67E-07	1.2E-09	0	0
		2030	Car	Petrol	g/km	Polynomial	0.830906	0.021877	0.000271	1.73E-07	1.21E-09	0	0
		2035	Car	Petrol	g/km	Polynomial	0.839806	0.022077	0.000272	1.76E-07	1.21E-09	0	0
GB	NOx	2003	Car	Diesel	g/km	Polynomial	14.5498	0.185192	0.00074	4.02E-05	-2.6E-07	2.01E-09	0
		2004	Car	Diesel	g/km	Polynomial	13.96619	0.179114	0.000754	3.73E-05	-2.3E-07	1.85E-09	0
		2010	Car	Diesel	g/km	Polynomial	7.31488	0.107253	0.000486	2.21E-05	-1.3E-07	1.05E-09	0
		2015	Car	Diesel	g/km	Polynomial	4.795879	0.075694	0.000366	1.52E-05	-8.7E-08	7.21E-10	0
		2020	Car	Diesel	g/km	Polynomial	2.852714	0.046521	0.000223	9.53E-06	-5.4E-08	4.5E-10	0
		2025	Car	Diesel	g/km	Polynomial	1.960241	0.032237	0.000154	6.64E-06	-3.8E-08	3.13E-10	0
		2030	Car	Diesel	g/km	Polynomial	1.72074	0.028266	0.000135	5.83E-06	-3.3E-08	2.75E-10	0
		2035	Car	Diesel	g/km	Polynomial	1.695186	0.027842	0.000133	5.74E-06	-3.3E-08	2.71E-10	0

Table 7: Speed-emission factor coefficients for fuel consumption from the fleet of rigid and artic HGVs in years 2003-2035. These coefficients are to be used in an equation of the form EF = (a + bx + $c.x^2$ + $d.x^3$ + $e.x^4$ + $f.x^5$ + $g.x^6$)/x where x is average speed in kph. The figures are consistent with the average mpg fuel efficiencies for HGVs given in DfT's CSRGT.

Region	Pollutant	Year	Vehicle type	Fuel type	Unit	Function	Coefficients						
						Type	a	b	c	d	e	f	g
GB	Fuel	2003	HGV - rigid	Diesel	litre/100km	Polynomial	206.5967	38.14245	-0.2377	-0.01343	0.0003874	-3.463E-06	1.1E-08
		2004	HGV - rigid	Diesel	litre/100km	Polynomial	195.4523	37.18253	-0.25304	-0.01202	0.000355	-3.158E-06	9.8E-09
		2010	HGV - rigid	Diesel	litre/100km	Polynomial	207.1291	34.50551	-0.12633	-0.01571	0.0004122	-3.604E-06	1.1E-08
		2015	HGV - rigid	Diesel	litre/100km	Polynomial	222.2635	32.40605	-0.01759	-0.01943	0.0004793	-4.205E-06	1.3E-08
		2020	HGV - rigid	Diesel	litre/100km	Polynomial	226.1316	31.87761	0.007053	-0.02034	0.0004975	-4.383E-06	1.4E-08
		2025	HGV - rigid	Diesel	litre/100km	Polynomial	226.3913	31.87816	0.007145	-0.02037	0.0004983	-4.392E-06	1.4E-08
		2030	HGV - rigid	Diesel	litre/100km	Polynomial	226.3913	31.87816	0.007145	-0.02037	0.0004983	-4.392E-06	1.4E-08
		2035	HGV - rigid	Diesel	litre/100km	Polynomial	226.3913	31.87816	0.007145	-0.02037	0.0004983	-4.392E-06	1.4E-08
GB	Fuel	2003	HGV - artic	Diesel	litre/100km	Polynomial	593.606	-15.7797	4.96073	-0.1902	0.0031933	-2.444E-05	7E-08
		2004	HGV - artic	Diesel	litre/100km	Polynomial	553.5392	-11.874	4.567523	-0.17682	0.0029754	-2.276E-05	6.5E-08
		2010	HGV - artic	Diesel	litre/100km	Polynomial	493.7537	-2.1118	3.85407	-0.15451	0.0026227	-2.002E-05	5.7E-08
		2015	HGV - artic	Diesel	litre/100km	Polynomial	478.6758	-0.19485	3.665079	-0.14827	0.0025222	-1.924E-05	5.5E-08
		2020	HGV - artic	Diesel	litre/100km	Polynomial	476.0918	0.127986	3.630602	-0.14712	0.0025036	-1.91E-05	5.4E-08
		2025	HGV - artic	Diesel	litre/100km	Polynomial	475.8388	0.191658	3.626733	-0.14700	0.0025019	-1.908E-05	5.4E-08
		2030	HGV - artic	Diesel	litre/100km	Polynomial	475.8388	0.191658	3.626733	-0.14700	0.0025019	-1.908E-05	5.4E-08
		2035	HGV - artic	Diesel	litre/100km	Polynomial	475.8388	0.191658	3.626733	-0.14700	0.0025019	-1.908E-05	5.4E-08

4 Use of Emission Curves in NTM

The spreadsheets provided to DfT have the coefficients a-g for calculating emission factors in g/km and fuel consumption in litre/100km from average speed for each main vehicle type in the fleet in years from 2003 to 2035. The spreadsheets demonstrate the calculation of emission factors from a speed using the polynomial equation (9).

All the emission curves defined by the coefficients in Equation (9) have a valid speed range outside of which the curves should not be used. This is particularly the case at the low end of the speed range. The spreadsheets provided gave the valid speed ranges for each vehicle type and pollutant and these are summarised in Table 8

Table 8: Valid speed range for speed-emission curves

	Vehicle type	**Valid speed range (kph)**
NO_x and PM_{10}	Petrol and diesel cars	5 – 120
	Petrol LGVs	5 – 100
	Diesel LGVs	5 - 120
	Rigid HGVs	6 – 90
	Artic HGVs	6 – 90
	Buses	6 – 75
	Coaches	6 - 105
Fuel consumption and CO_2	Petrol and diesel cars	5 - 140
	Petrol LGVs	5 – 100
	Diesel LGVs	5 - 120
	Rigid HGVs	6 – 90
	Artic HGVs	6 – 90
	Buses	6 – 75
	Coaches	6 - 105

The NTM needs to use emission factors calculated from these emission curves in conjunction with additional data relating to the fuel mix of vehicles and the bus/coach split of the PSV class of vehicles on different road types. Additional information is also required to account for taxis in London.

These additional data were provided to DfT in spreadsheet forms, and their use is summarised in this section.

4.1 Using the Curves to Derive Emission Factors in GB

At GB level, emission curves are provided for the following vehicle types:

- Petrol cars
- Diesel cars
- Petrol LGVs
- Diesel LGVs
- Rigid HGVs
- Artic HGVs
- Buses
- Coaches

The NTM needs the petrol/diesel split for cars and LGVs in order to use these emission curves with its vehicle km data and also the bus/coach split for the NTM's PSV class of vehicles.

The NAEI uses current DfT licensing statistics on the petrol/diesel mix of cars and LGVs and forecasts the fuel split in future years on the basis of the turnover in the fleet and the percentage sale of new diesel car/LGV sales as described in Section 2.4. It also takes account of the fact that diesel cars do 60% more mileage than petrol cars in a year and the decrease in annual mileage with vehicle age. A different petrol car/diesel car mix is assumed on different road types on the assumption that the additional mileage by diesel cars is done mainly on motorways and rural roads, whereas the mix on urban roads is assumed to be as represented by the mix in the vehicle population (in other words, there is no preferential use of diesel cars relative to petrol cars in urban areas).

For LGVs, the mix of diesel and petrol vehicles is assumed to be as indicated by the mix in the LGV population (i.e. there is no additional mileage done by diesel compared with petrol vehicles).

These assumptions lead to the following proportions of vkm done by petrol and diesel cars on urban, rural and motorway roads that should be used in the NTM.

Table 9: Proportion of car km by fuel type on urban, rural and motorway roads

		2003	2004	2010	2015	2020	2025	2030	2035
Urban	Petrol cars	83.2%	81.5%	70.4%	63.1%	59.4%	57.9%	57.2%	57.0%
	Diesel cars	16.8%	18.5%	29.6%	36.9%	40.6%	42.1%	42.8%	43.0%
Rural	Petrol cars	73.9%	71.6%	57.6%	49.4%	45.5%	44.0%	43.3%	43.1%
	Diesel cars	26.1%	28.4%	42.4%	50.6%	54.5%	56.0%	56.7%	56.9%
Motorway	Petrol cars	65.4%	62.7%	47.5%	39.4%	35.8%	34.3%	33.7%	33.6%
	Diesel cars	34.6%	37.3%	52.5%	60.6%	64.2%	65.7%	66.3%	66.4%

Table 10 provides the fuel split for LGVs and for these vehicles, the same split should be assumed on all road types:

Table 10: Proportion of LGV km by fuel type. The same values should be assumed for all road types

	2003	2004	2010	2015	2020	2025	2030	2035
Petrol LGVs	12%	10%	10%	10%	10%	10%	10%	10%
Diesel LGVs	88%	90%	90%	90%	90%	90%	90%	90%

As separate emission factors are provided for buses and coaches, the issue here is how to combine these in the NTM which uses a single category, 'PSV' to represent all types of buses. The NAEI assumes a constant bus/coach split for all years on urban and rural roads and assumes that only coaches use motorways. This leads to the bus/coach split shown in Table 11 which should be applied to the NTM's PSV vehicle category.

Table 11: Proportion or buses and coaches on urban, rural and motorway roads. The same split is assumed for all years

		All years
Urban/rural	Bus	72%
	Coach	28%
Motorway	Bus	0%
	Coach	100%

The split between buses and coaches on urban/rural roads was estimated from data showing the overall split in vkm by local bus services and other services.

4.1.1 An example of how to derive overall emission factors for cars on different roads

The use of the fuel mix data for cars on different road types in conjunction with the emission curves can best be illustrated by way of an example.

The aim is to derive an overall NO_x emission factor for cars in 2015 on an urban road with a speed of 40 kph and on a motorway with a speed of 100 kph.

For the urban road, the coefficients give a NO_x emission factor at 40 kph of 0.0674 g/km for petrol cars and 0.2309 g/km for diesel cars in 2015. In this year, the split in car km between petrol and diesel cars on urban roads is 63.1% and 36.9%, respectively (Table 9). Hence the overall car emission factor on urban roads is a weighted average of the petrol car and diesel car emission factors:

Car EF_{NOx} = (0.0674 x 0.631) + (0.2309 x 0.369)
= **0.1278 g/km**

For the motorway road, the coefficients give a NO_x emission factor at 100 kph of 0.0774 g/km for petrol cars and 0.2981 g/km for diesel cars in 2015. In this year, the split in car km between petrol and diesel cars on motorway roads is 39.4% and 60.6%, respectively (Table 9). Hence the overall car emission factor on motorway roads is a weighted average of the petrol car and diesel car emission factors:

Car EF_{NOx} = (0.0774 x 0.394) + (0.2981 x 0.606)
= **0.2111 g/km**

4.2 Using the Curves to Derive Emission Factors in London

For roads in London, a different set of emission curves is provided to take account of the London Low Emission Zone and also the specific known features of the bus and taxi fleets managed by TfL. Emission curves are provided for the following vehicle types:

- Petrol cars
- Diesel cars
- Petrol LGVs
- Diesel LGVs
- Rigid HGVs
- Artic HGVs
- London Buses
- Coaches entering London
- Taxis (black cabs)

For cars and LGVs, the fuel splits indicated by Tables 9 and 10 should be applied to these vehicles in London, i.e. there is no difference between the fuel mix for these vehicles in London compared with the rest of the GB.

For buses and coaches, a different bus/coach mix should be used to split the PSV vkm in London. The emission factors for buses in London (referred to as "London Buses") reflect the composition of the TfL fleet (which is assumed to contain no coaches) and other non-TfL buses operating in London. The bus/coach mix in the "Other buses operating in London" fleet is assumed to be the same as the rest of the GB, but the strong presence of TfL buses in London implies that overall, the proportion of coaches in the overall PSV fleet on roads in London is smaller than the rest of the GB.

The overall bus/coach split for London is shown in Table 12 which should be applied to the NTM's PSV vehicle category for London roads.

Table 12: Proportion or buses and coaches on roads in London. The same split is assumed for all years

	All years
London bus	93%
Coaches entering London	7%

Taxis (black cabs) are a sub-set of the car km in London, but a significant one and since the emission factors and fleet composition of the taxi fleet are quite different to ordinary cars, separate emission curves have been provided for taxis. To use the taxi emission curves, it is recommended that the car km figures for roads in London are broken down between ordinary cars and taxis and emission curves applied to each sub-set accordingly. Based on information from the London Atmospheric Emissions Inventory (LAEI), it is estimated that 3% of all car km in London as a whole (petrol and diesel) are done by taxis, but the fraction varies across different pars of London and is around 23% in central London, 2% in inner London and 0.1% in outer London. These figures could be used to split the car km figures from the NTM into cars and taxis to give an overall 'car' emission factor for cars and taxis in London, but it will depend on the level of area-type disaggregation for London as to whether the NTM can use separate taxi/car splits for central, inner and outer London or for London as a whole.

The use of the London-specific emission curves for buses and taxis will be illustrated in the following examples.

4.2.1 An example of how to derive overall emission factors for buses in London

The aim is to derive an overall PM_{10} emission factor for buses in 2010 on urban roads in London with a speed of 30 kph.

The speed-emission coefficients give a PM_{10} emission factor at 30 kph of 0.01576 g/km for 'London buses' and 0.14390 g/km for 'coaches entering London' in 2010. The split in 'all bus' (or PSV) km between London buses and coaches is 93% and 7%, respectively (Table 12). Hence the overall bus emission factor at this speed is a weighted average of the London bus and coach emission factors:

Bus EF_{PM10} = (0.01576 x 0.93) + (0.14390 x 0.07)
= **0.02473 g/km**

4.2.2 An example of how to derive overall emission factors for cars in Central London taking into account the effect of taxis

The aim is to derive an overall PM_{10} emission factor for 'all cars' in 2010 in Central London with a speed of 25 kph, reflecting the contribution made by taxis to the overall traffic flow for cars in Central London.

The speed-emission coefficients give a PM_{10} emission factor at 25 kph of 0.00180 g/km for petrol cars and 0.02537 g/km for diesel cars in 2010. In this year, the split in car km between petrol and diesel cars for ordinary cars on urban roads nationally is 70.4% and 29.6%, respectively (Table 9), and it is assumed this split applies to London. Hence the overall 'ordinary car' emission factor in London at this speed, excluding the contribution of taxis, is a weighted average of the petrol car and diesel car emission factors:

Ordinary Car EF_{PM10} = (0.00180 x 0.704) + (0.02537 x 0.296)
= 0.00878 g/km

However, 23% of all car km in central London are by taxis. The speed-emission coefficients give a PM_{10} emission factor at 25 kph of 0.05750 g/km for London taxis in 2010.

Hence, the overall PM_{10} emission factor for all cars in Central London in 2010 at this speed, including the effect of taxis is:

Overall Car EF_{PM10} = (0.00878 x 0.77) + (0.05750 x 0.23)
= 0.01999 g/km

5 National Emission Totals for Calibration

DfT required figures on total emissions of NO_x, PM_{10}, fuel consumption and CO_2 in 2003 and 2004 at GB level by main vehicle type from the NAEI model to effectively "calibrate" the baseline figures from the NTM using these emission curves.

Some differences in bottom-up estimates of emissions from the NTM and the NAEI can be expected for several reasons even though they are from the same source of emission factors and are based on the same input assumptions. One reason is the assumptions made about average vehicle speeds in the NTM and NAEI models and the number of vkm travelled at different speeds. The NAEI uses speeds from a variety of sources, including figures reported in DfT Statistics Bulletins and from the LAEI in the case of roads in London. Various sources, including outputs from the NTM model itself and also the 2007 Annual Average Daily Flow data from the DfT's national traffic census, are used by the NAEI to estimate the relative vehicle km travelled on different road and area types at different speeds. These speeds may not be the same as those used in the baseline NTM.

Another main reason for the differences is the NAEI figures include the contribution of cold start emissions, the excess emission that occur when a vehicle is started with its engine below normal operating conditions. The emission curves all refer to hot exhaust emissions.

Further details on the methodology and assumptions used to develop the current UK inventory for NOx, PM and CO_2 emissions from road transport are given in the methodology annex of the latest report on the UK's Greenhouse Gas Inventory (Jackson et al, 2009)[4]. However, certain assumptions (though not the raw NO_x and PM_{10} emission factors) are being revised for the 2008 version of the inventory currently in progress and the NO_x and PM_{10} emission curves developed for NTM will be consistent with these new assumptions used for the new inventory; for CO_2 the 2008 version of the inventory will use factors for buses further modified from those provided for the NTM due to new information being made available by DfT for the NAEI, as discussed below.

The NAEI model was used to provide figures on NO_x and PM_{10} exhaust emissions by main vehicle type in 2003 and 2004 at GB level. The NAEI normally provides emissions at UK level, by including emissions from traffic in Northern Ireland, but the Northern Ireland vkm was left out of the calculations to generate GB emissions. The NAEI also normally includes emissions from motorcycles, but these were left out of the calculations as this vehicle type is not covered in the NTM. The modelling methodology used is consistent with the emission factors and assumptions that underpin the emission curves and are those being used for the 2008 version of the NAEI (currently being developed).

Tables 13 and 14 show the GB emissions of NO_x and PM_{10}, respectively, in 2003 and 2004. These data were provided in spreadsheets to DfT and include the cold start emissions and exclude emissions from motorcycles. At GB level, emissions from London taxis are effectively covered in the car emissions.

Tables 15 and 16 show the corresponding GB figures for fuel consumption and CO_2 emissions, expressed in million tonnes fuel and CO_2. However, there is an important point to note about the NAEI figures for CO_2. The "official" figures on UK CO_2 emissions from road transport are constrained to be consistent with total fuel sales figures given in the Digest of UK Energy Statistics (DUKES). This is in accordance with rules for reporting national CO_2 emissions to the UN Framework Convention on Climate Change. The NAEI calculates fuel consumption from a bottom-up method, based on emission curves and vehicle km data, and typically finds a gap between the total calculated fuel consumption of petrol and diesel with those figures reported in DUKES (after correcting the latter for small amounts of these fuels used for off-road transport and machinery). The bottom-up NAEI figures by vehicle type are then normalised to match the DUKES figures and CO_2 emissions reported from the normalised figures. The gap between DUKES and the bottom-up estimates by vehicle type fluctuates from year-to-year and reflects both uncertainty in the fuel consumption factors, modelling methodology and activity data (e.g. the vehicle km figures) but also may reflect a real "fuel tourism" effect, whereby fuel is purchased abroad (and therefore not reported in DUKES) and consumed on UK roads, and *vice*

[4] http://www.airquality.co.uk/reports/cat07/0905131425_ukghgi-90-07_Annexes_Issue2_UNFCCC_Final.pdf

Table 13: GB emissions of NO_x from road vehicles based on the NAEI model

NO_x ktonnes		2003	2004
Car	Petrol	187.57	161.50
	Diesel	70.06	74.38
LGV	Petrol	9.18	6.62
	Diesel	72.57	73.31
HGV rigid		86.85	84.82
HGV artic		127.80	129.25
Bus		31.64	30.08
Coach		17.63	16.86
Total		**603.30**	**576.83**

Table 14: GB emissions of PM_{10} from road vehicles based on the NAEI model

PM ktonnes		2003	2004
Car	Petrol	1.020	0.981
	Diesel	5.776	5.699
LGV	Petrol	0.032	0.024
	Diesel	6.377	6.073
HGV rigid		2.205	1.990
HGV artic		2.903	2.808
Bus		0.612	0.546
Coach		0.424	0.393
Total		**19.350**	**18.515**

versa. The year-to-year fluctuations in the gap does lead to anomalies in the trends in the official fuel consumption and CO_2 emissions reported for individual vehicle types.

The figures provided in Tables 15 and 16 are "unconstrained", that is they are the bottom-up estimates based on the speed-emission curves and activity data consistent with the data provided for the NTM, without any normalisation to match with fuel consumption in DUKES, so provide a better set of data for "calibrating" the outputs from the NTM.

Initial bottom-up estimates on UK fuel consumption using these emission curves underestimated total petrol consumption by 3% in 2003 and 4% in 2004 compared with (adjusted) petrol sales figures in DUKES and overestimated total diesel consumption by 6% in 2003 and 5% in 2004 compared with (adjusted) diesel sales figures in DUKES. However, since the development of these emission curves for the NTM, a new set of fuel consumption factors has been developed for buses to align with new local bus fuel efficiency data provided by DfT from information on fuels purchased under the Bus Services Operators Grant system. This has modified the agreement between bottom-up fuel estimates and DUKES and led to a revision in the way the two methods are aligned.

Table 15: GB emissions of fuel consumption from road vehicles based on the NAEI model

FC Mtonnes		2003	2004
Car	Petrol	17.482	16.952
	Diesel	4.784	5.236
LGV	Petrol	0.500	0.430
	Diesel	3.837	4.104
HGV rigid		2.587	2.623
HGV artic		3.848	4.033
Bus		0.934	0.908
Coach		0.512	0.502
Total		**34.484**	**34.788**

Table 16: GB emissions of CO_2 from road vehicles based on the NAEI model

CO_2 Mtonnes		2003	2004
Car	Petrol	54.81	53.15
	Diesel	15.14	16.57
LGV	Petrol	1.57	1.35
	Diesel	12.14	12.99
HGV rigid		8.19	8.30
HGV artic		12.18	12.76
Bus		2.96	2.87
Coach		1.62	1.59
Total		**108.59**	**109.57**

6 Conclusions

A set of speed-emission curves has been developed for the NTM for NO_x, PM_{10}, fuel consumption and CO_2 covering each main vehicle class reflecting the composition of the fleet in terms of the proportion of vehicle km travelled by different Euro standards in the years 2003, 2004, 2010, 2015, 2020, 2025, 2030 and 2035. The factors also take account of the year-dependent effects of emission degradation with accumulated mileage and fuel quality on emissions. An additional set of curves has been developed for vehicles in London affected by the introduction of the Low Emission Zone and taking account of the effect of the specific TfL bus and taxi fleets operating in London.

The fleet-weighted emission curves are developed in the same form as the raw polynomial expressions developed by TRL on behalf of DfT for the more detailed vehicle categories, i.e. to a v^6 order. This means it would be straightforward to modify the fleet-weighted curves for the NTM if the raw expressions are updated (provided they are in the same polynomial form) or if the fleet composition is updated.

The fleet composition data and assumptions that underpin the emission curves and the method used to develop them are described in this report. The emission curves are designed to be used in conjunction with additional information relating to the fuel mix of vehicles (petrol and diesel cars and LGVs) and the bus/coach split of the PSV class of vehicles on different road types and the bus and taxi fleets operating in London. The use of these additional data with the factors derived from the emission curves are illustrated by means of a number of examples.

Finally, total emissions of NO_x, PM_{10}, fuel consumption and CO_2 in 2003 and 2004 at GB level by main vehicle type are provided from the NAEI model to effectively “calibrate” the baseline figures from the NTM using the emission curves. The reasons for differences anticipated between the NAEI estimates of GB emissions and NTM estimates derived using the emission curves are given, including the effects of cold start emissions and speed assumptions. For total fuel consumption and CO_2 emissions, a further issue needs to be considered when comparing the NTM results with “official” figures which are based on fuel sales figures in DUKES and how the NAEI’s bottom-up estimates of fuel consumption on a vehicle type basis are reconciled with the DUKES figures.

7 References

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