INFORMING AIR QUALITY MANAGEMENT STRATEGIES USING VEHICLE EXHAUST EMISSIONS DATA FROM REMOTE SENSING: A CASE STUDY OF LONDON

Glyn Rhys-Tyler

Postgraduate researcher

Transport Operations Research Group, Newcastle University

Professor Margaret C. Bell CBE

Science City Chair of Transport and the Environment

Transport Operations Research Group, Newcastle University

Abstract

Atmospheric pollutants have been the subject of regulation through national and international legislation for a number of years. In London, nitrogen dioxide and atmospheric particulates are the two main pollutants of concern within the draft Air Quality Strategy produced by the Greater London Authority. Most particulate emissions come from road transport (engine emissions, and tyre and brake wear). Road transport and heating systems are the main sources of nitrogen dioxide. A major survey of road vehicle exhaust emissions was carried out in London in 2008 using roadside remote sensing techniques. The surveys sampled the 'in-use' exhaust emissions of over 50,000 vehicles at 13 sites. Vehicles were uniquely identified from automatic number plate recognition data using the Driver and Vehicle Licensing Agency database. This permitted the characterisation of exhaust emissions by vehicle category, age, fuel type, engine capacity, and other parameters. Analysis of the data, combined with estimates of vehicle kilometres travelled, allows the estimation of the relative contribution of individual vehicle categories to the air quality problem. This provides an evidential basis for policy development and management interventions. The analysis highlights the growing significance of the 'dieselisation' of the passenger car fleet, and the non-linear relationship between emissions of oxides of nitrogen and vehicle age in diesel cars. Interesting insights are also provided into the exhaust emissions characteristics of the public transport fleet, and the highly dynamic nature of the situation overall through time. The Greater London Authority is currently considering a range of policy interventions within the Air Quality Strategy, including extending the scope of the existing Low Emission Zone standards, introducing an age limit for taxis, and adopting tougher emissions standards for buses.

1. Road transport and local air quality

Atmospheric pollutants have been the subject of regulation through national and international legislation for a number of years. The European Union has recently adopted Directive 2008/50/EC on ambient air quality and cleaner air for Europe, consolidating previous legislation, which sets out limit values for a range of pollutants considered harmful to human health. These include limit values for nitrogen dioxide (NO_2) and particulates (PM_{10}). In London, NO_2 and particulates are the two main pollutants of concern within the draft Air Quality Strategy. Most particulate emissions come from road transport (engine emissions, and tyre and brake wear). Road transport and heating systems are the main sources of NO_2. The draft Air Quality Strategy notes that whilst NO_2 is of most concern due to its impact on health, the control of total NO_x (NO_2 + NO) is essential because of the ease with which nitric oxide (NO) converts to NO_2 in the atmosphere (Greater London Authority, 2010).

Given the significance of road transport as a source of air pollution, the European Union has adopted increasingly stringent regulations to control the composition of exhaust emissions within the vehicle type approval process. Current European vehicle type approval legislation regulates levels of NO_x (oxides of nitrogen) in exhaust emissions, but not specifically NO_2, an apparent discontinuity in European regulatory policy highlighted by Carslaw and Beevers (2004). This issue has become more significant in the UK in recent years because of the increasing proportion of diesel fuelled passenger cars in the UK fleet. In the UK, 33% of new passenger cars registered in 2004 were diesel; in 2009, this percentage increased to 41% (DoT, 2010). Diesel (compression ignition) engines tend to produce higher levels of NO_x and particulates compared to petrol (spark ignition) engines. Diesel engines also emit a higher proportion of their NO_x as NO_2 compared with petrol engines (Alvarez et al, 2008). Vehicle manufacturers have utilised a range of exhaust treatment technologies to achieve compliance with the increasingly stringent type approval limits, including three-way catalytic converters (TWC), exhaust gas recirculation (EGR), selective catalytic reduction (SCR), diesel oxidation catalysts (DOC), and diesel particulate filters (DPF) (Bosch, 2007), in addition to seeking improved combustion efficiency through engine design and fuel chemistry. However, researchers such as Carslaw (2005) and Grice et al (2009) have highlighted the significance of diesel particulate filters, and other exhaust after treatment systems for diesel engine vehicles, in the increasing formation of primary NO_2, and a subsequent increase in the local NO_2/NO_x ratio due to road traffic.

Despite the significant developments in vehicle technology, road vehicles continue to have a significant negative impact on UK local air quality. Currently, 59% of UK local authorities (237 out of 405) have one or more Air Quality Management Areas (AQMA's) declared, because air quality objectives in regulation cannot be met by specified target dates. Road traffic emissions are the main source in 92.5% of the AQMA's declared (mainly due to NO_2 and PM_{10} pollution); only a small number have been designated as a result of industrial sources, domestic or shipping emissions (DEFRA, 2009).

Given the dynamic nature of the UK vehicle fleet, and the significance of the environmental challenges facing policy makers, there is relatively little detailed current information available in the literature about the 'in-use' environmental characteristics of road vehicles in the UK. Some studies were carried out in London in the 1990's measuring carbon monoxide (CO) and hydrocarbons (HC) (Sadler et al, 1996; Muncaster et al, 1996; Revitt et al, 1999), using roadside remote sensing, but both instrumentation and fleet characteristics have evolved over the intervening period. A European Joint Commission Services Study into 'In-use vehicle emission controls', carried out in 1994-1998, included roadside remote sensing measurements at a number of locations, including two locations in the UK. The study assessed the effectiveness of remote sensing as a method of screening the vehicle fleet for high emitters, and found a high Emission Reduction Rate Potential (ERRP) for CO and HC, and a more moderate reduction potential for NO and fuel consumption (Barlow, 1998). The EU FP5 REVEAL project developed a low cost roadside remote sensing device (RSD) to collect data on overall car fleet emissions characteristics and gross emitters, which included a field trial in London in 2003 (REVEAL, 2004). The REVEAL RSD was later used in Winchester, Hampshire in 2006 to research driver motivation for voluntary vehicle emissions related maintenance (Felstead, 2007).

Remote sensing is a practical and cost effective method of collecting emissions data for a large sample of vehicles, and as such can be a useful complement to more detailed dynamometer and instrumented vehicle measurements. It has the potential to provide statistically robust fleet emission characteristics through repeat measurements over a sustained period of time (McCrae et al, 2005). This paper describes the exhaust emissions characteristics of a sample of vehicles operating in London in 2008, based on data collected using roadside remote sensing absorption spectroscopy techniques (infrared and ultraviolet), combined with Automatic Number Plate Recognition (ANPR) for vehicle identification, and vehicle speed/acceleration measurement. Using this information, the 'in-use' emissions characteristics of the observed vehicles can be determined, by vehicle class, fuel type, vehicle age, and engine capacity. This information allows the estimation of the relative environmental impact of each vehicle category for each atmospheric pollutant, informing the development of future environmental and transport policies at the local and national level, and highlighting research issues meriting more detailed investigation.

2. London remote sensing exhaust emissions measurements 2008

The analysis utilises a pre-existing dataset supplied by colleagues at Southwark Council and Ealing Council. The data were collected in 2008 using an RSD 4600 on-road vehicle emissions testing device manufactured by Environmental Systems Products. The equipment was owned and operated by Enviro Technology under contract (Merelles, 2008). The development and application of this equipment and measurement technique is described extensively in the literature (Bishop et al, 1989; Burgard et al, 2003, Burgard et al, 2006; Bishop and Stedman 2008). The RSD 4600 measures three gas ratios; CO/CO_2, HC/CO_2, and NO/CO_2. These ratios are used in a combustion equation in real time (making reasonable assumptions about fuel composition, and air/fuel ratio for stoichiometric combustion) to produce estimates of the values of CO%, CO_2%, HCppm, and NOppm. NO_2 is not measured directly. The instrument also measures smoke, reported in units of grams of diesel particulate per 100 grams fuel, based on opacity measurements made at ultraviolet wavelengths in the 230 nm UV spectral range (Stedman and ESP, 2004; ESP, 2005).

The surveys were carried out at 8 sites in Ealing in March/April 2008, and 5 sites in Southwark in June/July/August 2008, over a total of 29 survey days, resulting in over 119,000 observations. The different survey seasons resulted in a range of mean ambient temperature, from 5.8°C to 27.0°C, and a range of relative humidity, from 39% to 86%, which has potential implications for use of vehicle ancillaries such as air conditioning, and for duration of cold start operating conditions. Other studies in the literature which were carried out specifically to monitor 'hot' vehicle emissions (e.g. Sjodin and Andreasson, 2000; Ekstrom et al, 2004), selected survey sites where vehicles were generally warmed-up (i.e. with the catalytic converter operating at optimum temperature). The road network in question was subject to a 30mph (48kph) speed limit for all survey sites, but speeds through the survey sites would be influenced by local context and traffic management measures used for the surveys (e.g. signing, traffic cones etc.). The majority of survey sites had moderately positive (uphill) gradients where the engine of the vehicle would be under moderate load. Measured mean speeds through the survey sites were in the range 5.9 to 10.4 m/s; measured mean accelerations were in the range 0 to $+0.5 m/s^2$. Given that this analysis utilises a pre-existing dataset, it was not possible to control the survey design, and it is considered likely that the data contains a proportion of vehicles operating in cold-start mode. It can be considered that the surveys were therefore measuring the exhaust emissions from road vehicles on the urban road network in London operating across a range of representative operating modes, including cold starts, and their consequent overall contribution to local air quality in London.

Vehicles were uniquely identified using the vehicle registration plate (or licence plate) number. The survey dataset included a digital photograph of the rear of each vehicle. From this, it was possible to carry out data cleaning and validation of the ANPR process. A total of 99,847 vehicle registration licence plate numbers were generated from this process. These 'cleaned' licence plate numbers were then matched against the central UK vehicle registration database maintained by the UK Driver and Vehicle Licensing Agency (DVLA), resulting in 94,328 matches (identified vehicles). Not all survey observations were successful (valid) emissions measurements. 66304 observations had valid emissions measurements (as determined by the instrument acceptance criteria logic). Overall, 54599 observations had both valid emissions measurements and vehicle identification.

Vehicles were classified according to the type approval classes defined in Commission Directive 2001/116/EC (European Parliament, 2001), i.e. passenger vehicle classes M1, M2, and M3; commercial vehicle classes N1, N2, and N3. In addition, category M1 was further subdivided to allow separate analysis of the emissions characteristics of passenger cars and London taxis (black cabs) respectively. The DVLA data included date of manufacture for the matched vehicles. This was used to estimate applicable European emission standards. However, the use of vehicle age as a proxy for emissions standard may not be a completely reliable method, particularly for London taxis and buses, as will be discussed later.

3. Vehicle age profile

As discussed above, there are growing concerns about some of the environmental disbenefits associated with the 'dieselisation' of the passenger car fleet in the UK, in particular relating to production of NO_x, primary NO_2 and particulates. Figure 1 presents the passenger car age profile of the observed fleet by the main fuel types, petrol and diesel. For vehicles manufactured in 1997, 9.7% are diesel; for vehicles manufactured in 2007, 40.8% are diesel. This figure increases to 42.7% in 2008, broadly consistent with total UK fleet statistics.

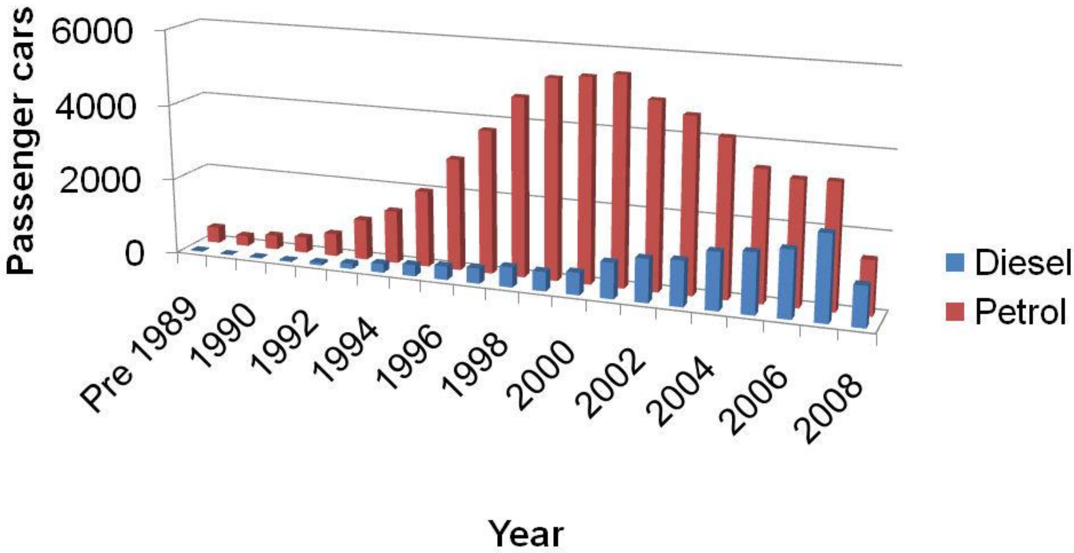

Figure 1: Observed passenger fuel type by year of manufacture

The average age of petrol cars is 7.5 years, whereas the average age of diesel cars is 4.9 years. This reflects the growing popularity of diesel powered vehicles in recent years, consistent with Figure 1. Therefore, on average, diesel cars in the observed fleet will tend to have newer technology, including emissions control technology, compared to petrol cars. The average age of the observed London taxis (black cabs) is 7.1 years, marginally longer than the overall age of the total car fleet. The average age of the observed large (M3) buses was 6.8 years, but fleet acquisition tends to be in tranches, and particular groups of vehicles will tend to be allocated to particular routes, and thus be observed in the surveys on multiple occasions.

4. Exhaust emissions from passenger cars

Table 1 presents a summary of observed vehicle exhaust emissions by vehicle class, fuel type, and emissions standard, where data sample bins contain generally more than 100 observations. Mean and median values are presented for CO, HC, NO, and smoke. The divergence of mean and median values in the data is indicative of the presence and influence of large values in the tails of the distribution of data. Previous studies have identified the skewed and leptokurtic nature of the distribution of emissions data (Zhang et al, 1994), and that a relatively small number of gross emitters tend to generate the majority of total fleet pollutant (Sjodin and Andreasson, 2000).

Cars and taxis (category M1) comprised just under 80% of the observed vehicles. CO, HC, and NO emissions from petrol cars are all seen to display a decreasing trend with the introduction of each successive (and more stringent) Euro standard, from Pre-Euro through to Euro 4. The mean and median CO and HC values for Euro 4 are both approaching zero. The distribution of petrol cars by age has a bearing on the overall fleet average emissions values. The high number of Euro 2 petrol cars (10,811) with relatively high levels of emissions, results in the group average emissions being significantly higher than the later Euro 4 vehicles, particularly when considering the mean values (including gross emitters) rather than the median (50th percentile) values. Figure 2 presents the NOppm for the observed petrol and diesel cars in the form of box plots. The extent of the reduction in NO emissions for petrol cars by each successive Euro standard is demonstrated clearly.

Table 1

Observed vehicle emissions by vehicle class, fuel type, and emissions standard

				Carbon monoxide (CO)		Hydrocarbons (HC)		**Nitric oxide (NO)**		Smoke number	
Vehicle type	Fuel type	Emissions class[1]	n	**Mean**	***Median***	Mean	*Median*	**Mean**	***Median***	Mean	*Median*
				%	***%***	ppm	*ppm*	**ppm**	***ppm***		
M1 (Car)	Petrol	Pre Euro	1306	1.853	0.946	983	564	955	595	0.20	0.18
		Euro 1	4271	0.806	0.289	356	126	451	179	0.05	0.02
		Euro 2	10811	0.490	0.130	206	41	320	84	0.03	0.01
		Euro 3	13312	0.168	0.033	56	4	105	23	0.01	0.01
		Euro 4	4647	0.066	0.019	14	-3	49	12	0.00	0.00
		Total	34347	0.399	0.067	170	16	240	48	0.03	0.01
	Diesel	Pre Euro	88	0.067	0.035	78	47	510	434	0.24	0.16
		Euro 1	499	0.071	0.042	73	37	476	410	0.23	0.16
		Euro 2	1012	0.061	0.037	78	52	628	535	0.20	0.15
		Euro 3	3537	0.039	0.013	37	25	486	376	0.15	0.10
		Euro 4	2861	0.020	0.010	23	16	294	203	0.08	0.06
		Total	7997	0.037	0.015	40	24	435	331	0.14	0.09
	Hybrid	Euro 4	120	0.072	0.020	16	-4	1	0	0.00	0.00
	Total[2]		42603	0.330	0.046	145	18	276	78	0.05	0.02
M1 (London taxi)	Diesel	Euro 1	121	0.008	0.008	31	17	975	881	0.12	0.10
		Euro 2	213	0.012	0.009	19	13	928	858	0.14	0.11
		Euro 3	209	0.006	-0.002	48	27	414	311	0.43	0.36
		Euro 4	121	0.000	0.006	17	14	327	249	0.19	0.12
	Total[2]		690	0.013	0.007	31	18	665	612	0.23	0.14
M3 (Bus)	Diesel	Euro 2	901	0.013	0.012	70	50	841	777	0.08	0.04
		Euro 3	850	0.017	0.015	88	50	1001	884	0.12	0.05
	Total[2]		1824	0.016	0.014	80	51	946	853	0.10	0.05
N1 (Light Commercial)	Diesel	Euro I	916	0.074	0.051	116	71	711	566	0.28	0.18
		Euro II	840	0.070	0.042	91	59	687	568	0.25	0.16
		Euro III	3540	0.055	0.021	60	33	623	497	0.23	0.16
		Euro IV	2761	0.031	0.010	40	22	363	253	0.15	0.09
	Total[2]		8115	0.050	0.020	63	33	557	428	0.21	0.14
N2 (Medium Commercial)	Diesel	Euro III	245	0.081	0.060	78	42	1412	1205	0.14	0.12
		Euro IV	127	0.069	0.039	49	30	1327	1226	0.09	0.06
	Total[2]		439	0.081	0.055	87	46	1407	1232	0.15	0.11
All vehicles[2]			54599	0.279	0.038	136	22	357	137	0.08	0.03

[1]Emissions class estimated from vehicle year of manufacture. This assumption is questionable for London taxis and buses.
[2]Values include additional data from small sample bins.

In contrast, observations of NO from diesel passenger cars display an interesting characteristic which merits further investigation. NO emissions increase from Euro 1 to Euro 2, before decreasing when the Euro 3 standard is applied. This phenomenon becomes clearer when the emissions data are reviewed on an annual basis, by year of manufacture, as presented in Figure 3. When interpreting these data, one should be aware that the sample size is increasing by year of manufacture, as diesel powered vehicles become a larger proportion of the fleet. NO emissions increase from year 1995 (mean 457ppm, median 400ppm) to a maximum in year 2000 (mean 676ppm, median 596ppm), then gradually decline to 2008 (mean 283ppm, median 200ppm). The explanation for this may be related to the prevailing type approval emissions standard in force at the time.

The transition from Euro 1 to Euro 2 for diesel cars introduced a significant reduction in the CO limit value from 2.72g/km to 1.00g.km over the test cycle. There was also a tightening of the particulate (PM) limit, and a reduction in the combined HC+NO_x limit. However, an individual limit for NO_x was not introduced until the Euro 3 standard was adopted (DoT, 2007). When Euro 3 was introduced with an explicit NO_x limit value, NO_x was reduced.

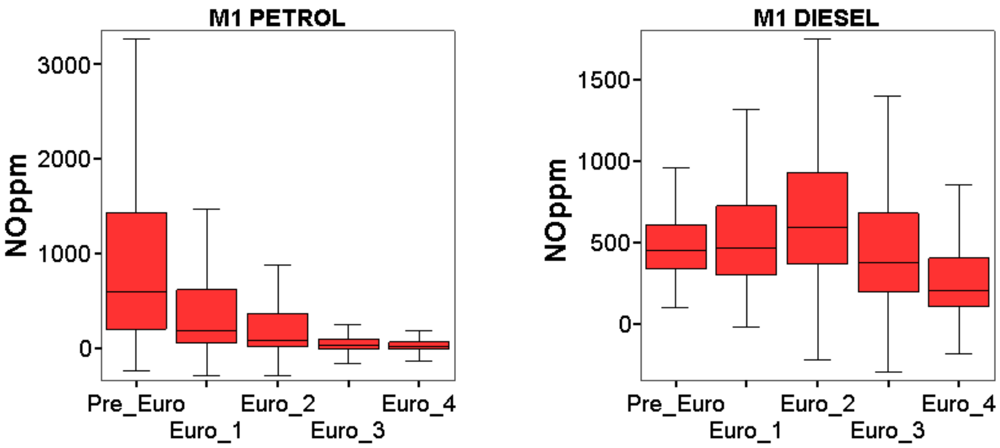

Figure 2: Nitric oxide (NOppm) emissions from the observed M1 vehicles (cars and taxis) by fuel type and Euro class, presented as box plots. Outliers and extreme outliers have been excluded for reasons of presentational clarity.

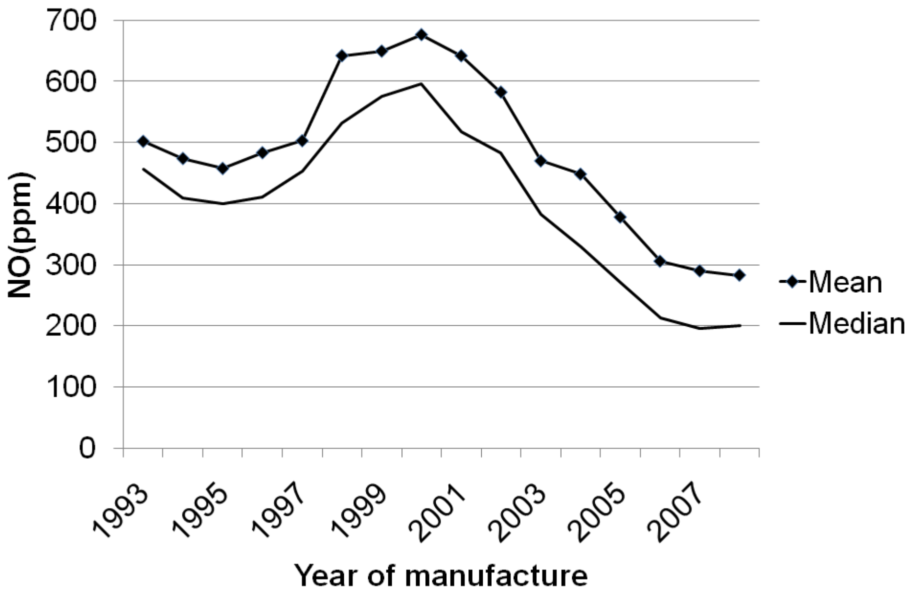

Figure 3: Nitric oxide (NOppm) emissions from the observed diesel cars by year of manufacture.

5. Exhaust emissions from London taxis

London taxis (black cabs) are subject to an annual licensing regime, which includes emissions standards. Since June 30th 2008, annual licences have only been issued to taxis that meet Euro 3 standards (TfL, 2010). This is achieved either by (a) operating a vehicle originally manufactured to Euro 3 standards, (b) retro-fitting approved emissions reduction equipment, or (c) using an LPG conversion. The taxi emissions strategy was implemented in two phases. At the time of the surveys in 2008, all LTI type vehicles registered before September 16th 1998 should have been adapted to comply with the Euro 3 standard for NO_x and PM_{10}. From July 1st 2007, annual licences were only issued if the vehicle was Euro 3 compliant for NO_x and PM_{10}.

This highlights one of the limitations of using vehicle age as a proxy for Euro standard. Although some of the remote sensing surveys were carried out before the taxi emission strategy had been fully implemented, some degree of homogeneity might be expected in the results, as nearly all would have been technically Euro 3 compliant.

The sample size for the London taxis is significantly smaller than for the diesel cars. Further, the mean engine capacity for the diesel cars is 2.10 litres, whilst the mean engine capacity for the London taxis is 2.56 litres. The London taxis display a more pronounced and clearly defined 'step' down from Euro 2 to Euro 3, with Euro 1 and Euro 2 emitting mean NO values of 975ppm and 928ppm respectively, and Euro 3 and Euro 4 emitting mean NO values of 414ppm and 327ppm respectively. At the time of the surveys, it can be seen that vehicles originally manufactured before 2001 are emitting more than double the NO compared to vehicles manufactured after this date. This suggests that even if all of the vehicles are technically Euro 3 compliant (with retro fitted emissions control equipment), use of vehicles registered from 2003 onwards will result in significantly lower emissions of nitric oxide into the atmosphere.

Table 1 highlights an anomaly in the smoke number measurements for taxis. The smoke numbers for Euro 3 vehicles are more than double the other Euro classes. Figure 4 presents the NO and smoke number results for the observed taxis by year of manufacture. There is a distinct 'peak' in smoke number in the range year 2002 to year 2006, before falling sharply in 2007. This may be a consequence of the well documented trade-off between NO_x and particulates in diesel engine emissions control. However, a more detailed analysis of the changes in vehicle technology in the London taxis suggest that changes in engine technology may explain the sharp transitions. Up until around 2002, the LTI London taxis were powered by a Nissan 2.7 litre engine. With the introduction of the LTI TXII taxi in around 2002, a Euro 3 compliant Ford 2.4 litre engine was adopted. Finally, the LTI TX4 taxi was introduced around 2006 with a VM Motori 2.5 litre engine.

This leads to the tentative conclusion that a pre 2002 model taxi (with retro fitted emissions control equipment) will produce significantly lower smoke (particulates) exhaust emissions than a post 2002 LTI TXII model taxi, but with much higher emissions of nitric oxide. Only with the introduction of the LTI TX4 model taxi are both particulates and NO_x reduced together. Therefore, a simple policy of reducing the average age of the taxi fleet <u>may</u> in some circumstances result in a net increase in emissions of particulate matter.

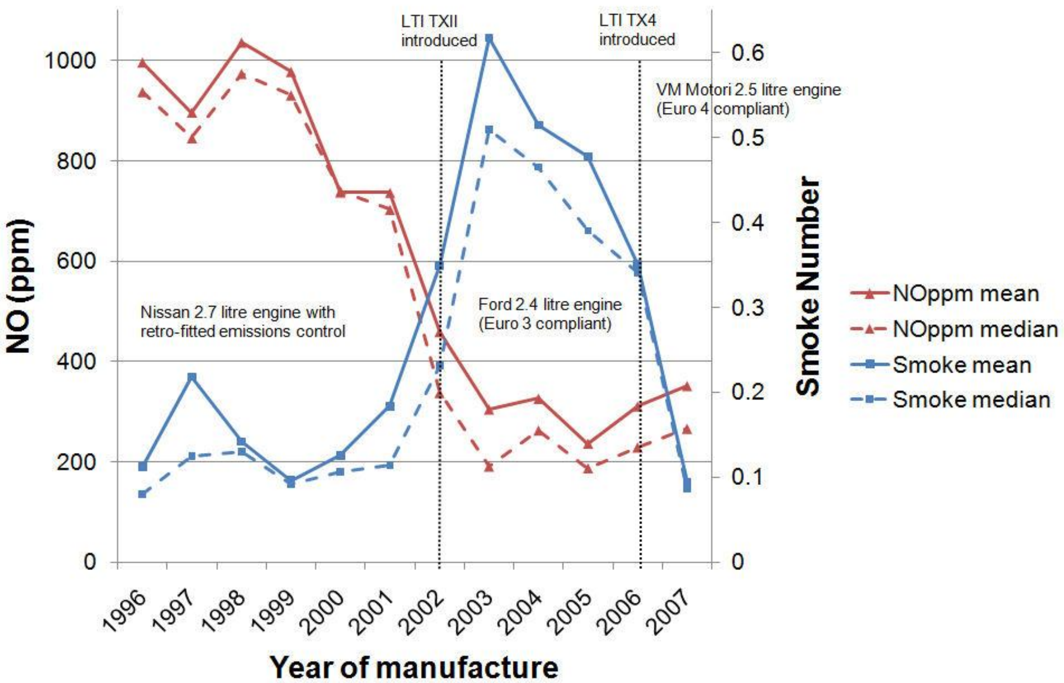

Figure 4: Comparison of nitric oxide (NOppm) and smoke (grams of particulate per 100 grams of fuel burnt) emissions from the observed diesel taxis by year of manufacture.

N.B. Sample sizes for observed taxis are relatively small (in the range 35 to 67 observations for each year of manufacture). Further research is required to determine whether this apparent taxi particulate issue is significant for future environmental policy in London.

6. Exhaust emissions from London buses

Most observed buses were either Euro 2 or Euro 3 emissions standard based on year of manufacture. However, since December 2005, all buses operating under Transport for London (TfL) contract have been Euro 3 compliant for particulate matter (to comply with the requirements of the Low Emission Zone), with older vehicles being retrofitted with diesel particulate filters (TfL, 2008). The measured CO values were extremely low (Euro 2 CO mean 0.013%, Euro 3 CO mean 0.017%). Observed HC values were low also (Euro 2 HC mean 70ppm, Euro 3 HC mean 88ppm), with identical median values of 50ppm, although the Euro 3 observations displayed more variability. A slightly clearer difference was observed in the NO measurements (Euro 2 NO mean 841ppm, Euro 3 NO mean 1001ppm). The higher NO emissions values for Euro 3 buses relative to Euro 2 buses were slightly unexpected. Although NO is not specifically regulated for vehicle type approval, it might be expected that NO would decrease with NO_x, which is regulated for type approval. Unfortunately, specific measurements of NO_2 were not available in this study, to determine the NO/NO_2 ratio in NO_x. This anomaly merited more detailed investigation.

Bus (M3) is the only vehicle category that is geo-spatially constrained, i.e. buses are generally allocated to fixed routes. Inspection of the data reveals that; (a) there is a mix of different bus vehicle types (both make and model) operating through the survey sites; and, (b) the proportion of different vehicle types (both make and model) varies by survey site. Some sites were surveyed in March/April 2008 (Spring), whereas the other survey sites were implemented in June/July/August 2008 (Summer), when average ambient daytime temperatures were respectively around 10ºC and 22ºC. Previous studies have reported extracts from the TfL exhaust emissions database, showing that tailpipe NO_x emissions for different bus types can vary by a factor of over 2, even within the same Euro class (DEFRA, 2007). Overall, there is a large degree of variability of measured NO emissions for different bus makes, models, Euro classes, and ambient temperatures. As with taxis, the results for buses should be treated with some caution because of the relatively small sample sizes, and in some instances multiple observations of the same vehicles within samples.

7. Gross emitters and overall emissions contribution by vehicle class / Euro standard

As noted in earlier, previous studies have shown that a relatively small proportion of the vehicle fleet produce the majority of polluting exhaust emissions. Table 2 presents the proportion of exhaust emissions produced by the most polluting 5% of observed vehicles from the London 2008 data.

Table 2

Proportion of exhaust emissions produced by the most polluting 5% of observed vehicles

Vehicle type	CO	HC	NO
Petrol cars	47%	52%	44%
Diesel cars	59%	39%	17%
All cars	51%	55%	36%
All observed vehicles	56%	55%	29%

The high emissions proportions for petrol and diesel powered cars are not the same, illustrating the differences in the underlying frequency distribution of the emissions data for different fuel types. As emissions limits become more stringent with each new Euro standard, the absolute level of emissions is decreasing, but CO and HC are still observed to display a skewed and peaked distribution. The NO (and to a lesser extent, HC) emissions of diesel cars are less skewed, with the most polluting 5% of cars emitting a far lower proportion of total emissions.

Figures 5 presents observed NO exhaust emissions by vehicle year of manufacture in the form of deciles (arithmetic means), for petrol and diesel cars respectively. These plots serve to illustrate more clearly both the changes in emissions characteristics by year of manufacture, and the change in the shape of the emissions distribution (i.e. the relative contribution of each decile to the total emissions). The form of the emissions distribution varies by year of manufacture, pollutant, and fuel type. The form of the distribution for petrol cars illustrates the absolute reduction in NO emissions with the introduction of the Euro 1 standard, with relatively high values persisting in the eighth and ninth deciles until around 2001 when the Euro 3 standard begins to penetrate the fleet. The distribution of NO emissions for diesel cars has a different form. From Euro 1 standard onwards, NO emissions from diesel cars are higher than petrol cars, and one does not observe the level and rate of NO emission reduction as is observed in the petrol fleet. The distribution is relatively less skewed and more platykurtic in nature.

(a) Petrol cars (b) Diesel cars

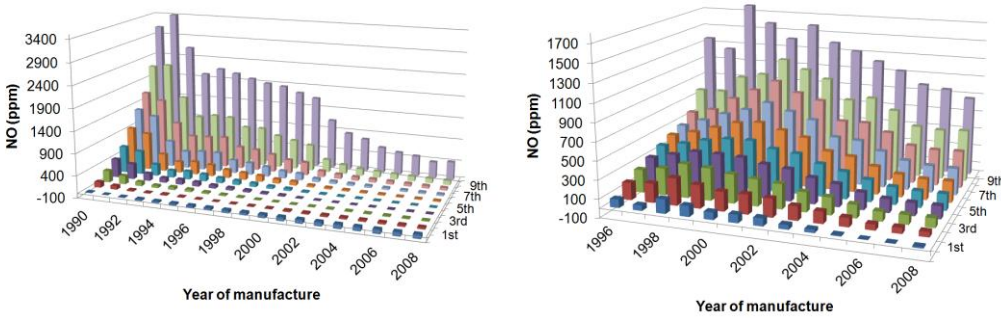

Figure 5: Observed NO exhaust emissions by vehicle year of manufacture (deciles, arithmetic means) for petrol and diesel cars respectively

Whilst a small number of older (Pre Euro) vehicles may individually be the most polluting in the fleet, the total emission contribution of each vehicle class and Euro standard is obtained by calculating the emissions weighted by the total number of vehicles in each class and the vehicle kilometres driven. Vehicle kilometres are not available directly within this study, although multiple observations at survey sites provide some indication of usage rather than just vehicle stock. When emissions measurements are weighted by number of observations in this study, petrol cars (sum of all Euro classes) are observed to emit 90% of CO, 79% of HC, and 42% of NO. Diesel cars emitted 18% of NO, and diesel light commercial vehicles (N1) emitted 23% of NO. When individual Euro classes are considered, the most polluting emissions group is Euro 2 petrol cars which were observed to emit 35% of all CO, 30% of HC, and 18% of NO. Clearly, when considering public policy interventions to reduce exhaust emissions from road traffic, one should consider not only the emissions characteristics of different vehicle types and Euro classes, but also the absolute numbers of these vehicles operating by road type, the average age of each class (rate of fleet turnover), the vehicle kilometres driven, and trends in vehicle ownership.

8. Informing the London Air Quality Management Strategy

The draft Air Quality Management Strategy for London identifies a range of possible interventions to help mitigate the negative environmental impact of road transport, building on measures already proposed or underway. Measures already proposed or underway include:

- Bus emissions programme – from 2012 every new bus coming into the London fleet will be diesel-electric hybrid;
- Operation of the London Low Emission Zone, which reduces emissions from older, heavier diesel vehicles (currently focussed on particulate matter emissions);
- Procurement and promotion of electric vehicles;
- ‘Greening’ of transport fleets – for example, phased replacement for Dial-a-Ride vehicles and 1,000 electric vehicles in the GLA fleet by 2015.

Proposals under consideration in the draft Strategy include:

- Introducing a ‘no idling zone’ with a particular focus on buses, coaches, taxis and delivery vehicles
- By 2015 all buses in London to meet the Euro IV standard for NO_x, through the specification of new buses and retrofitting of older buses
- Seek ways to accelerate the take up of cleaner, new vehicles into the taxi fleet including introducing age-based limits for taxis. It is proposed that from 2012 no licence will be issued for a taxi over 15 years old. From 2015 it is proposed that this age limit will tighten to ten years;
- Introduce a requirement for all new taxis entering the fleet to meet a minimum Euro 5 standard from 2012
- Introduce into the licensing regime age-based limits for Private Hire Vehicles. A ten year rolling age limit will be applied for vehicles being re-licensed from 2012 onwards.
- Introduce a requirement for all new Private Hire Vehicles entering the fleet to meet a minimum Euro 4 standard from 2012
- Include heavier LGVs and minibuses in the Low Emission Zone from an appropriate point in 2012
- In 2015, introduce an emissions standard for NO_x (Euro IV across London) into the Low Emission Zone for HGVs, buses and coaches.

Based on the analysis of data from remote sensing of road vehicle exhaust emissions, it is clear that when proposing policy interventions such as age-based limits on certain vehicle categories, the relationship between environmental performance, age, and technology should be considered carefully to ensure that unintended consequences are avoided. In particular, policy should consider all relevant pollutants, and their relative importance locally and strategically, given that in emissions control technology there is often a trade-off between controlling one pollutant or another.

The growing body of research evidence indicating that modern diesel engines are emitting increasing levels of primary NO_2 should be of significant concern in the context of the developing Air Quality strategy. The take up of diesel cars in the UK is increasing year on year, but has not yet reached the very high levels observed in some parts of continental Europe. Appropriate policy stimuli, whilst recognising the fuel efficiency advantages of diesel technology relative to petrol, should consider the negative consequences of particulate matter and NOx (NO and NO_2).

9. Conclusions

The adoption of increasingly stringent vehicle emissions standards for type approval has been very successful in reducing exhaust tailpipe emissions in general. In London, mean CO and HC emissions in 2008 were around 25% and 14% respectively of the levels observed in the mid 1990’s. However, the use of new exhaust treatment technologies to meet Euro 5 (2009) and Euro 6 (2014) emissions standards for diesel vehicles may have unintended consequences in terms of exacerbating pollutants which are not currently subject to vehicle type approval limits (e.g. NO_2), with possible negative impacts on local air quality.

The Mayor’s draft Air Quality Strategy (Greater London Authority, 2010) has highlighted the importance of addressing road transport sources of NO_x ($NO+NO_2$) and particulates if local air quality is to comply with regulatory standards in the long term. This study has confirmed the significance of the continuing ‘dieselisation’ of the UK passenger car fleet and its implications for local air quality in general, but has also highlighted a number of issues relating to particular vehicle classes which merit further research. The draft London Air Quality Strategy includes a package of potential interventions including the adoption of Euro 4 emissions standards for buses, introducing an age limit for taxis, and introducing a new NO_x standard for the LEZ for commercial vehicles and buses, but decision making needs to be based on evidence. The use of remote sensing data in this analysis has shown that large volumes of relevant quantitative information can be generated using relatively non-invasive techniques. Knowledge gained from this data can be used to inform evidence based decision making, identifying the contribution of each vehicle class to local emissions, and helping to determine which package of interventions will be most likely to create a successful overall strategy.

It is clear from the data and national statistics (DoT, 2010) that the UK vehicle fleet composition and environmental performance is highly dynamic. Remote sensing is a practical tool to carry out repeat observations at reasonable cost to establish and quantify longitudinal trends. It offers the ability to provide statistically robust fleet emission characteristics through repeat measurements over a sustained period of time (McCrae et al, 2005). Consideration should be given to the value of such a future programme of measurements in the context of the wider air quality management strategy.

10. Acknowledgements

This work was part funded by the EPSRC FUTURES project and Newcastle University. The authors are grateful to colleagues at Southwark Council and Ealing Council for the supply of data, and we acknowledge with thanks the role of Transport for London in the original data collection project. The authors wish to acknowledge the assistance of Dr Linda Davies at Imperial College for help with documentation.

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