Transactions on Ecology and the Environment vol 15, © 1997 WIT Press, www.witpress.com, ISSN 1743-3541

A high resolution atmospheric emissions inventory for road vehicle sources and the factors influencing its accuracy and sensitivity

R C Mann and R S Sokhi
Atmospheric Science Research Group (ASRG), Department of Environmental Sciences, University of Hertfordshire, College Lane, Hatfield, Hertfordshire, AL10 9AB, UK
EMail: r.s.sokhi@herts.ac.uk

Abstract

This paper discusses the factors that need to be considered when developing a high resolution 1x1 km^2 emissions inventory and describes their application to a 625 km^2 area within Hertfordshire, UK. The emissions of CO and NOx from motor vehicles are estimated by 5 classes of vehicle and 5 different road types. An assessment is made of the proportions of emissions within urban and rural areas together with those created by cold starts. Trends in emissions for the years 2000 and 2005 are estimated. The high levels of CO emissions from urban driving and cold starts are identified and the level of reductions achievable from the use of three way catalysts are discussed. The uncertainties in the data and their sensitivity to the results are considered and quantified.

1 Introduction

Emission inventories which provide an estimate of the emissions for a particular time period and spatial area are used as the basis for dispersion modelling to estimate concentrations of pollutants at specific locations. Thus it is important to recognise the limitations in their preparation and the associated accuracy [1]. The development of a 1x1 km resolution emission inventory provides an opportunity to identify the major factors that influence the inventory results. This level of resolution has been chosen to identify the primary sources of emissions on urban and rural roads within a small region and to support the development of finer scale air quality models. The spatial and temporal trends provide information of the effects of local, regional and national changes on the emissions for the area. Such information is important for the effective management of air quality [2].

The inventory covers a geographic area of 625 km^2 and includes several large towns, three major motorways with traffic counts above 140000 per day, and a network of primary and local roads. It is a mixed urban and rural community on the outskirts of London without any major point sources of pollution and with motor vehicles being the source of most primary pollutants. At a national level the proportions from traffic sources are estimated at 93% for CO and 48% for NOx (Eggleston [3]).

Data from 1994 have been used to produce the base inventory and this is updated for the years 2000 and 2005 using forecasts of traffic and emission changes. In generating the inventories, the input parameters were assessed to identify their accuracy and their importance to the final result.

2 Method

2.1 Factors that need to be considered in assessing vehicle emissions

Emissions from a specific vehicle will vary by the type of fuel it is designed to use and the weight, age and engine size of the vehicle. They will also be affected by its speed distribution, the distance travelled and the engine and ambient temperature [1] on each journey undertaken.
(i) Type of Fuel. The primary sources considered are petrol and diesel.
(ii) Weight, age and engine size of the vehicle. A UK classification system from Eggleston [3] is used to define five main groups of vehicles:
1. Two wheeled motor vehicle (TW)
2. Buses and coaches
3. Car
4. Light Goods Vehicle (LGV) up to 3.5 tonnes
5. Heavy Goods Vehicle (HGV) up to 38 tonnes in the UK.

Within each of these groups there can be subgroups based on engine size and the emission regulation applicable to different ages of vehicle.
(iii) Speed and distance travelled. Factors that will influence the speed are the type of road being traversed, the driver's style, the power of the vehicle, the load being carried, statutory speed limits and the extent of congestion.
(iv) Engine temperature.There is a significant increase in emissions arising from an engine that has not reached its normal operating temperature (Holman et al [4]). This is known as the cold start penalty. In general, a cold engine requires a higher fuel to air ratio than at normal temperatures and pollutants such as CO and VOC, which are the result of incomplete combustion, will be increased. More importantly, in cars with closed loop three way catalysts (TWC), the catalyst will operate only when it has reached a temperature of 500 °C. With

current technology this takes a few minutes during which any pollutants that are emitted remain unchecked.

2.2 Calculation of emission factors for the inventory

To determine emission factors each group of vehicles has been considered separately and where information is available, they have been sub-divided by weight, engine size and age.

(i) Two Wheeled Motor Vehicle (TW). CORINAIR[5] provides values relating to vehicles of either < 50cc or > 50cc but no information about variability by speed or age. A composite emission factor is calculated on the assumption that the >50cc group are 2-stroke and 4-stroke in equal proportions.

(ii) Cars. Using the UK vehicle licensing statistics [6], the proportions of vehicles in 1994 with petrol or diesel engines, different engine sizes and different levels of regulatory emission control were identified. CORINAIR emission factors were chosen as it was the only source that provided comprehensive data for each sub-group at various speeds. To determine a representative speed distribution for motorways and rural roads, the proportions of cars travelling within specific speed ranges were identified from the UK Transport statistics [7]. It was assumed that vehicles were able to travel at a constant speed with little stop/start motoring and few junctions. This distribution was used with the vehicle fleet proportions and CORINAIR factors to calculate a composite emission factor for each vehicle sub-group.

For urban roads the same fleet proportions were applied to a speed distribution based upon vehicles within Central London at peak time. Although this might be thought to be extreme for average urban vehicle movement, it was interesting that the resulting composite emission factor was comparable and, for TWC cars, lower than those of Salway et al [8] who have produced some recent emission factors for the UK fleet.

For local roads the emission factor has to take account of cold starts. As described in 2.1 a cold engine and cold TWC mean that a TWC car can emit an order of magnitude more pollutant than a hot engine over its first kilometre of operation. During an average journey of 10 km at an ambient temperature of 10 °C, 72% of total CO emissions and 55% NOx are produced within the first kilometre [4]. The CORINAIR emission factors for hot engines were used, multiplied by a factor for cold operation, and applied to the fleet proportions to calculate a composite emission factor applicable for the first kilometre.

(iii) Buses. CORINAIR does not identify this vehicle class specifically, so Salway et al [8] data was used for motorway, urban and rural road types.

(iv) LGVs. Salway et al [8] data was used in preference to CORINAIR for the base emission factors for this group as the data is more appropriate to the UK fleet and more recent. Licensing statistics [6] show there are 49% petrol and 51% diesel LGVs in the 1994 fleet. These proportions were used to calculate composite emission factors for the fleet.

(v) HGVs. The proportions of the fleet with different vehicle weights and level of regulatory control was established from the licensing statistics [6] and composite emission factors calculated utilising data from Salway et al [8].

The resulting composite emission factors are shown in table 1.

Emission factors g/km	CO					NOx				
	m/w	rural A	Urban A,B,C	Rural B,C	Cold start	m/w	Rural A	Urban A,B,C	Rural B,C	Cold start
TW	18.8	18.8	18.8	18.8		0.16	0.16	0.16	0.16	
Car 1994	4.9	5.0	16.0	5.2	30.4	2.84	1.48	1.61	2.17	1.83
Car 2000	3.9	3.5	8.2	3.1	17.8	1.72	1.48	0.98	1.29	1.30
Car 2005	3.5	2.6	3.7	2.0	10.9	0.97	0.81	0.54	0.81	0.92
Bus 1994	1.8	7.3	18.8	7.3		13.00	13.89	15.66	13.89	
Bus 2000	1.8	7.3	18.8	7.3		11.64	12.00	14.11	12.00	
Bus 2005	1.8	7.3	18.8	7.3		10.50	10.43	12.81	10.43	
LGV 1994	11.2	5.0	9.0	5.0		2.64	1.49	1.60	1.44	
LGV 2000	10.3	4.6	8.3	4.6		2.19	1.25	1.37	1.25	
LGV 2005	9.5	4.2	7.6	4.2		1.74	1.00	1.14	1.00	
HGV 1994	2.5	3.5	6.3	3.5		14.94	15.98	14.11	15.98	
HGV 2000	1.8	3.8	5.5	3.8		9.73	8.74	10.39	8.74	
HGV 2005	1.8	3.8	5.5	3.8		8.65	7.68	9.28	7.68	

Table 1: Calculated CO and NOx emission factors for each vehicle type in fleet

2.3 Estimation of total emissions

To obtain an emissions inventory for road vehicles it is necessary to sum emissions from every journey of every vehicle within the designated time period and to apportion them spatially as required. The current approach is to consider the journey as the sum of stages upon one or more of the road classes that make up the road network. In the UK the roads are classified as:

1. Motorways (national network of through routes)
2. A class road (trunk and primary routes between major towns and cities)
3. B class road (secondary distributor roads within regional areas)
4. C class road (local distributor roads)
5. Local and estate roads

In preparing the inventory vehicle counts were associated with each section of road within each square. In the cases where counts are not directly available for a specific road link, a value is estimated using averages of any nearby, similar class roads. In the case of Motorway and A roads the Department of Transport counts were available subdivided by the 5 vehicle categories described in 2.1; for B and C roads the numbers per vehicle category were estimated from Hertfordshire Traffic Data Report [9] using a county-wide proportion. The product of vehicle counts and link lengths provides an estimate of the vehicle ‘flow’ for each link. Each flow was assigned either to an urban classification where there was a 30 or 40 mph speed limit in force within the

Transactions on Ecology and the Environment vol 15, © 1997 WIT Press, www.witpress.com, ISSN 1743-3541

grid square or to a rural classification otherwise. Table 3 shows the total vehicle kilometres (Vkm) travelled within the inventory area. The emissions are then calculated from Vkm and derived emission factors. Mann et al [10] provides more information on the method used.

The emissions from cold starts were based upon the number of journeys made by households within each 1x1 km square. The Department of Transport's 'Trip end model presentation program' (TEMPRO) [11] provides estimates of journeys per household; it was assumed that each journey consisted of a 1 kilometre portion upon local estate roads (therefore it is not double accounted with other vehicle count data) using a car with a cold engine at an ambient temperature of 10 °C.

Total Vkm $x10^3$/day	TW	Car	Bus	LGV	HGV	Total
Motorway	47	6022	50	658	949	7726
Rural roads	43	3509	30	368	221	4171
Urban roads	55	4487	48	474	236	5300
Cold start		982				982
Totals	145	15000	128	1500	1406	18179

Table 3: Vehicle kilometres (Vkm) by each vehicle class within the inventory area

2.4 Future trends for overall emissions

The inventory has been re-calculated for the year 2000 and 2005. This involved changes to the composition of the vehicle fleet and hence to the emission factors. With more TWC cars becoming part of the fleet there is a decrease in the CO emission factors for all road types, with significant drops in those from urban driving. LGVs and HGVs have small reductions in their emission factors because of improved statutory controls on emissions from new vehicles. There is a similar but less dramatic reduction in NOx emission factors over the 10 year period. The assumptions made are:

1. the number of TW, Buses, LGVs and HGVs will remain unchanged
2. the vehicle kilometres travelled will increase by the proportions derived from UK Transport Statistics [7]. See table 4.
3. the car population will grow by the proportion given in table 4.
4. the sales of diesel cars will continue at 1994 levels and thus will increase from 7.4% of total fleet in 1994 to 14.2% in 2000 and to 18.5% in 2005.

	TW Vkm	Car numbers	Car Vkm	Bus Vkm	LGV Vkm	HGV Vkm
Year 2000	100	113	115	100	116	112
Year 2005	100	123	127	100	131	124

Table 4. Predicted growth in numbers of cars and Vkm for each vehicle type normalised to 100 in 1994

3 Results

3.1 Emissions Inventory

The detailed 1x1 km inventory is not reproduced here because of lack of space. It demonstrates that CO emissions are concentrated within the urban areas and NOx emissions occur more on motorways. For more details see Mann et al [10].

3.2 Comparison of emissions by vehicle type and road use

Figure 1 shows the contribution to total CO from each class of vehicle and each class of road use. From these it can be seen that TW at 2% are negligible in the UK. Buses are < 1% and HGVs <3% resulting from the low CO emission factors of diesel vehicles.

Cars at 87% are the primary source of CO with LGVs contributing 8%. Urban driving contributes 47% with a further 17% arising in urban areas from the cold start penalty on local roads. Motorway driving contributes a further 24% as a result of the high Vkm (42% of total) from all vehicle types and the higher emission factors associated with LGVs at speed.

Figure 2 shows the contribution to total NOx from each class of vehicle and each class of road use. In this case cars and HGVs contribute 55% and 36% respectively of NOx. Motorway driving contributes 58% of the pollutant since NOx emissions from cars increase at high speed and there are higher numbers of HGVs found on such roads. Cold starts on local roads are negligible at 3%. The remaining NOx emissions are evenly spread amongst urban and rural roads with cars and HGVs again the primary sources. TW are less than 0.1% of the total and do not register on the chart at this scale.

3.3 Future emissions by vehicle and road use

Figure 3 shows the trends for CO by vehicle and road use. TW and Buses grow fractionally from their 2% or 1% of the total. In both cases the emission factors used have not been reduced for future years; this will probably lead to over-estimation of emissions as new legislation is likely to reduce emission factors. Car CO emissions reduce to about 46% of their 1994 levels of 54 KTonnes whilst absolute LGV figures climb slowly. Thus the LGV proportion of the total rises from 4.9 KTonnes (8%) to 5.5 KTonnes (16%) in 2005. CO from HGVs also increases slightly and their proportion of the total rises from 3% to 5%. The quantity of CO attributed to motorways is roughly constant during the three periods and therefore rises from 23% to 41% as a proportion of the total. Urban and cold start emissions decline as a result of TWCs on cars.

Figure 4 shows the trends for NOx by vehicle and road use. Here NOx from cars declines to 46% of the 1994 figure whilst LGV and HGV have much smaller reductions and hence an increased proportion of the total NOx

Transactions on Ecology and the Environment vol 15, © 1997 WIT Press, www.witpress.com, ISSN 1743-3541

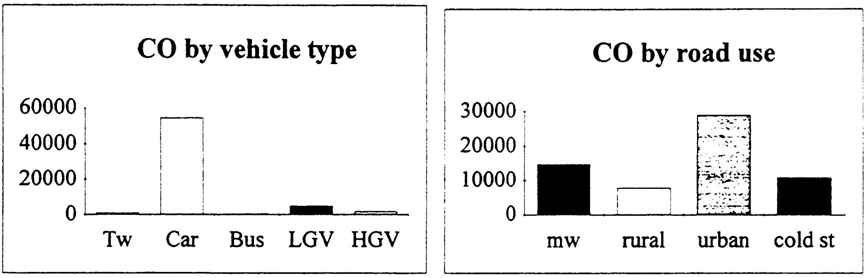

Figure 1: 1994 CO emissions in tonnes per annum by vehicle type and by road use

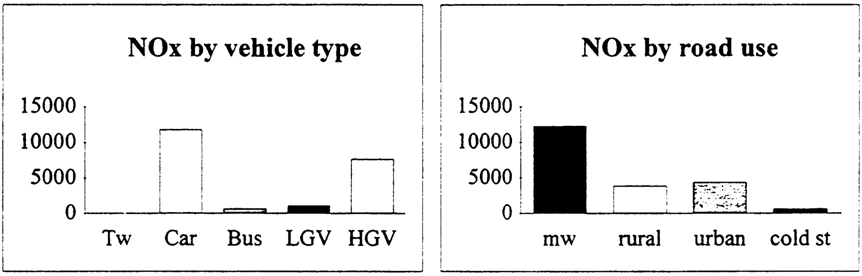

Figure 2: 1994 NOx emissions in tonnes per annum by vehicle type and by road use

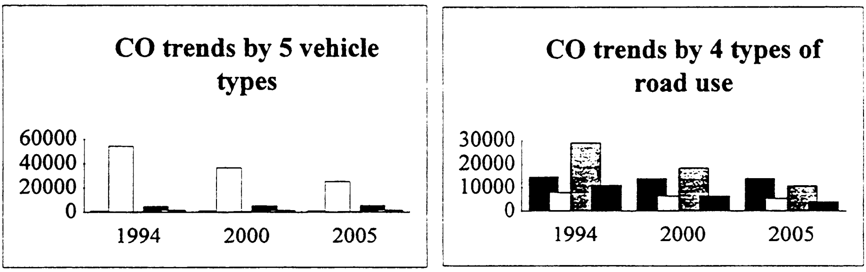

Figure 3: Trends in CO emissions (tonnes per annum) by vehicle types and by road use
(For each year, box shading follows the same sequence as figure 1)

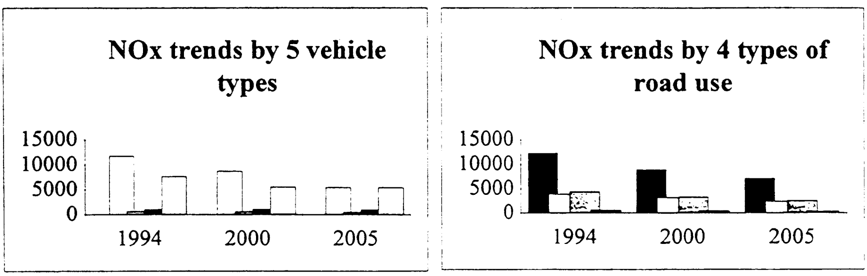

Figure 4: Trends in NOx emissions (tonnes per annum) by vehicle types and by road use
(For each year, box shading follows the same sequence as figure 2)

emissions. The total motorway emissions fall from 12.3 to 7.2 KTonnes but remain at about 57% of the total. This results from the increasing proportion of TWC cars in the fleet during the period up to 2005.

4 Discussion

4.1 Uncertainty and sensitivity of emissions inventory

The factors used in developing the inventories have been assessed to identify those which contain the greatest uncertainties in their estimation and which will have the greatest effect on the final inventory. They are listed in table 5 where the * indicates the relative order of effects. In the 'uncertainty' column, * represents low uncertainty and **** high uncertainty of the input data. In the 'sensitivity' column, * represents a small effect on the total inventory and **** represents a major effect on the inventory.

4.2 Sensitivity of emissions inventory

This section considers in more detail those factors where uncertainty in their estimation will lead to significant changes to the final emissions inventory. The main areas identified all apply to CO emissions.

1. For TWC cars in urban areas this work uses an emission factor of 1.5 g/km calculated from CORINAIR with a representative speed distribution. Salway et al [8] on the other hand suggests a figure of 3.3 g/km but do not provide details of the calculation procedure. Incorporating this higher figure in the 2005 predictions would lead to an increase of 32% in urban emissions.
2. For motorway driving the TWC car emission factor calculated from CORINAIR is 4.0 g/km compared to 1.1 g/km from Salway et al. Based on this study the implication is that Salway et al may have under-estimated 2005 motorway emissions by 133%.
3. For cold starts of TWC cars, a figure of 9.0 g/km for emissions within the first kilometre has been calculated from CORINAIR. Other sources [8 and 5] suggest figures of 12.2 g/km and 43.4 g/km respectively. The higher figure would lead to a 220% increase in 2005 cold start emissions.
4. TWC have been fitted to petrol LGVs since 1995. Salway et al show the emission factor reducing by about 22% on the introduction of catalysts to such vehicles. However they also show reductions of over 80% being achieved when TWC are fitted to cars. If a similar improvement could be achieved for LGVs, urban emissions from LGVs will reduce by 44% and motorway emissions by 48%.

Factor	Comments	Uncertainty of data	Sensitivity to inventory CO	Sensitivity to inventory NOx
Road network and lengths	GIS systems provide accurate data	*	****	****
Vehicle counts - motor ways and major roads	Counts are made on a tri-annual basis on one day. They are factored to provide an average day's data	**	****	****
Vehicle counts - minor roads	Detailed counts on one day. Limited coverage of the road network	**	***	***
Fleet composition - type, age, fuel used	Licensing statistics are comprehensive for most vehicle types.	*	****	****
Fleet composition - engine size	Good for cars; LGVs not specifically identified	**	**	**
EFs - TW and buses	One figure for all conditions	****	*	*
EFs - petrol and diesel cars	Limited data for urban and congested conditions	***	****	**
TWC for cars and petrol LGVs	Limited research on the frequency of failure and their effectiveness in congested or high speed motoring	***	***	***
EFs - LGVs	Limited data for all road conditions.	****	**	**
EFs - HGVs	Variation between loaded and empty vehicles not known. Limited data on the effect of high motorway speeds.	****	**	***
EFs - cold starts	Different techniques and limited research data	****	****	*
Number and length of journeys	Effect on cold start estimations	***	***	*
Future fleet composition	Difficulties in trend analysis; changes in ratio of diesel/petrol cars	***	****	****

Table 5: Assessment of factors used in developing an emissions inventory (EF - Emission Factor).

5 Conclusions

CO and NOx emissions have been computed for 5 classes of vehicle on a 1 km resolution for a mixed urban and rural area. Forecasts of emissions for the years 2000 and 2005 have been made. At present cars generate the majority of CO emissions and they occur mainly during urban and cold start operation. The introduction of TWC from 1993 leads to a significant reduction of urban/cold start emissions in the period to 2005 despite traffic growth. By 2005 the level of

CO emissions on motorways is almost equal to that of urban+cold start emissions because TWC have little effect on CO emissions during high speed driving.

For NOx, cars and HGVs are the primary sources and the emissions occur mainly during motorway driving as a result of the higher level of emissions at speed. During the period up to 2005, TWC reduce the level of car emissions and the two vehicle types emit similar amounts at that time. Emissions on motorways still predominate.

The study highlights that emission factors for TWC cars, their continued effectiveness and emissions from cold starts are key factors in determining an accurate inventory. The identified variations in published emission factors shows the need for publication of the detailed calculations incorporating the congested speed patterns that exist in many urban areas.

Index

High resolution emissions inventory; Emission factors; CO pollutant; NOx pollutant; Future emissions

References

1. *The Environmental Assessment of Traffic Management Schemes: a Literature Review.* Transport Research Laboratory Report 174, 1995

2. The *United Kingdom National Air Quality Strategy*, HMSO, UK, 1997

3 Eggleston HS, *Pollution in the Atmosphere: Future emissions from the UK.* Report number LR888 AEA technology, Culham, Oxfordshire, UK, 1992

4 Holman C, Wade J, Fergusson M, *Future Emissions from cars 1990-2025: the Importance of the Cold Start Emissions Penalty.* A Report for WWF UK, Earth Resources Research, London, 1993

5 Eggleston HS, Gaudioso D, et al. *CORINAIR working group on Emission factors for calculating 1990 Emissions from Road Traffic.* Commission of the European Communities contract number B4-3045(91) 10PH, 1992.

6 *Vehicle Licensing Statistics 1994.* HMSO,UK, 1995

7 *Transport statistics Great Britain 1994.* HMSO, UK, 1995

8 Salway AG, Eggleston HS, Goodwin JWL, Murrells TP. *UK Emissions of Air pollutants 1970 - 1994.* AEA technology, Culham, Oxfordshire, UK, 1996

9 *Hertfordshire Traffic Data Report 1994*, Hertfordshire County Council, Transportation, Hertford UK, 1995

10 Mann RC, Sokhi RS, Nakorn N, Development and Interpretation of High Spatial Resolution Atmospheric Emission Inventories for CO and NOx incorporating Road Traffic Sources. *Proceedings of Air and Waste Management Association Conference,* New Orleans, 1996

11 *TEMPRO: trip end model presentation program*, Department of Transport, London, UK, 1994