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The Perth Vehicle Emissions Inventory, 2006–2007

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The Perth Vehicle Emissions Inventory 2006–2007

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Executive summary

The Perth airshed has been identified as a priority for diffuse emissions reporting as part of the Australian National Pollutant Inventory (NPI). Air quality modelling at the W.A. Department of Environment and Conservation (DEC) uses inventories, mainly developed in-house, for particles, air toxics and photochemical smog modelling. The original inventory was based on the year 1992, with a later update based on the 1998-1999 period. In addition, a diffuse emissions study was undertaken by a consultant on behalf of DEC based on the 2004-2005 period.

Due to major changes in the pattern of motor vehicle emissions, an update of the vehicle emissions inventory has been completed based on the years 2006-2007.This new inventory resolves some issues which arose from errors in input vehicle kilometres travelled (VKT) data, and includes significantly more detail in the time variation of traffic flows. These additions will become increasingly important for future projections, which show considerably more congested traffic flow. The new inventory has estimated total annual emissions of principal pollutants from all vehicular categories for the Perth airshed, in both 2001/2002 and 2006/2007 are presented.

In this study, the magnitude of evaporative emissions under different scenarios such as winter, summer and high-oxidant scenarios were examined and evaporative emissions weightings calculated for these scenarios. Separate daily temporal profiles were derived for the evaporative VOC emissions, as evaporative emissions are significantly affected by changes in ambient temperature.

Significant differences were observed between vehicle emissions on typical summer days, winter days and high-oxidant days. Total annual emissions for speciation of VOC (selected substances) from on-road mobile sources in the Perth airshed were also calculated from total VOC emissions. The daily profile and hourly variations in VOC, CO and NOx emissions for fleets in Perth airshed are also presented in this report.

1 Introduction

The Perth metropolitan airshed has been identified as a priority emissions inventory area as part of the National Pollutant Inventory (NPI) program. The NPI is an Australian Government program that records air pollution sources and their emissions across Australia. The NPI enables the general public to access information about toxic air pollutants being emitted in their region.

The Western Australian Government's Department of Environment and Conservation (DEC) has developed local emissions inventories for air toxics and other air pollutants for Perth. These local emissions inventories are used by the DEC in air quality modelling programs.

Of the wide range of sources contributing to the pollutant load in the Perth airshed, the emissions resulting from motor vehicles have been identified as being the single largest contributor, accounting for more than 80% of the carbon monoxide (DEP, 2000). As the number of vehicles and vehicle kilometres travelled (VKT) increases, there is a need to ensure that strategies are in place to manage transport emissions, both in the immediate and long term.

The original Perth airshed emissions inventory was compiled for the year 1992, with a later update based on the 1998/1999 period (DEP 2002). In addition to these inventories, a diffuse emissions study was undertaken by a consultant on behalf of DEC based on the 2004/2005 period. Due to the rapidly increasing number of motor vehicles in the Perth metropolitan area, an update of the vehicle emissions inventory has recently been completed based on the years 2006/2007.

The 2006/2007 vehicle emissions inventory contains significantly more detail in relation to the time variation of traffic flows in the Perth area than previous inventories. This new emissions inventory resolves some issues which arose from errors in input vehicle kilometres travelled (VKT) data, and includes more detail in the time variation of traffic flows compared to the 1992 emissions inventory. These additions are becoming increasingly more important for future vehicle fleet projections for Perth.

1.1 Vehicle emissions inventory years

The vehicle emissions inventory results presented in this report are emissions modelled for the 2006/2007 calendar year based on node-and-link model data of the region's significant roads provided by Main Roads WA. These data represent the road network for the Perth airshed, for the years 1996, 2001, 2006, 2011, 2016, 2021 and 2031.

1.2 Study region

The Perth airshed study region measures 90 km east-west by 162 km north-south, which corresponds to a total area of 14,580 km^2 (Figure 1). In order to account for spatial variation in emissions over the region, the region was subdivided into a network of grid cells. Emissions were spatially allocated to grid cells measuring 3 km by 3 km. For the Perth airshed study region, this approximates to 30 by 54 grid cells or a total of 1620 data points across the spatial domain.

1.3 On-road emission source categories

Five main categories were considered as on-road emission sources: (1) petrol passenger cars, (2) petrol light duty commercial vehicles and (3) diesel heavy duty commercial vehicles, (4) diesel light duty vehicles and (5) other vehicles (i.e. motorbikes, campervans, etc). Each category contains several vehicle subcategories based on fuel type and vehicle body code. The composition and behaviour of evaporative emissions for each vehicle and fuel type varies from that of exhaust emissions and as such are treated as a separate category.

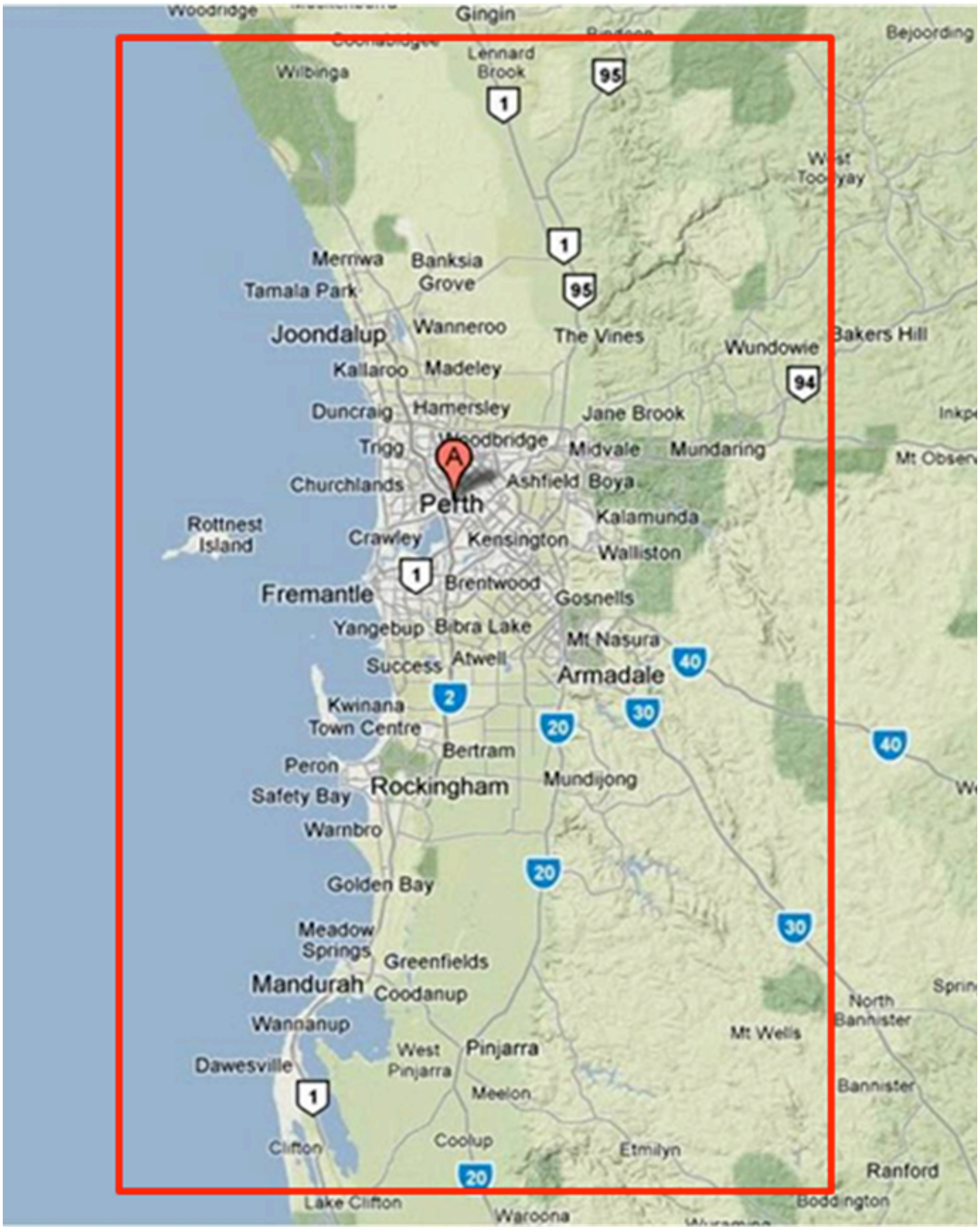

Figure 1. Location of the vehicle emissions inventory study region

2 Methodology

2.1 Spatial allocation of emissions

The vehicle emissions inventory results presented in this report are base on emissions modelling for 2006/2007 based on a node-and-link model of the region's significant roads using data provided by Main Roads WA. A ‘node’ in this representation is normally a road junction and a ‘link’ is a segment of a road running between nodes.

Vehicle emissions estimates were spatially allocated on a grid coordinate system of 3 km by 3 km grid cells. The grid coordinates start from the bottom left corner having index number increasing with Easting (km) in the horizontal and Northing (km) in the vertical direction. The coordinates of this area are defined as lower left corner northing- easting of 6,364,000 and 364,000; and upper right corner northing-easting of 6,526,000 and 454,000.

Road junctions (nodes) and segments of a road running between nodes (links) corresponding to the year to which the network applies were considered in the inventory modelling. Each link is unidirectional, so that there are two links in the file for any segment of the road network. This matter becomes important when traffic congestion is considered, since a road may experience a morning traffic flow peak in one direction, and an evening peak in the other. In order to use these emission data for the emissions inventory purposes, the road network data was allocated to a grid system where each road link is broken up into sub-links which did not extend beyond the borders of an individual grid square.

2.2 Activity data

The relative vehicle kilometres travelled (VKT) by vehicle/fuel type for each road type may be derived by applying Australian Bureau of Statistics (ABS) data to the total VKT in the airshed listed by vehicle/fuel type to the figures for relative VKT by vehicle type. That is, the fractions of VKT on a road type by a particular vehicle type (e.g. passenger vehicles) may be further distributed to each vehicle/fuel type combination (e.g. petrol, diesel and LPG fuelled passenger vehicles) by applying ABS estimates of the proportions of VKT in the jurisdiction by each of these vehicle/fuel types (NPI, 2000).

The relative VKT for each road type may be derived from ABS data and total VKT data in the airshed. The estimate of relative VKT for selected municipal areas, road and vehicle types provided by Main Roads WA was based on a representative selection of road lengths and traffic information on road classifications across Western Australia including the Perth metropolitan area. The study updated estimates from an earlier (2001/2002) Main Roads WA project, which was an attempt to estimate VKT for freeways, arterial and local roads (Figure 2). The distribution of vehicles based on fuel type is shown in Figure 3.

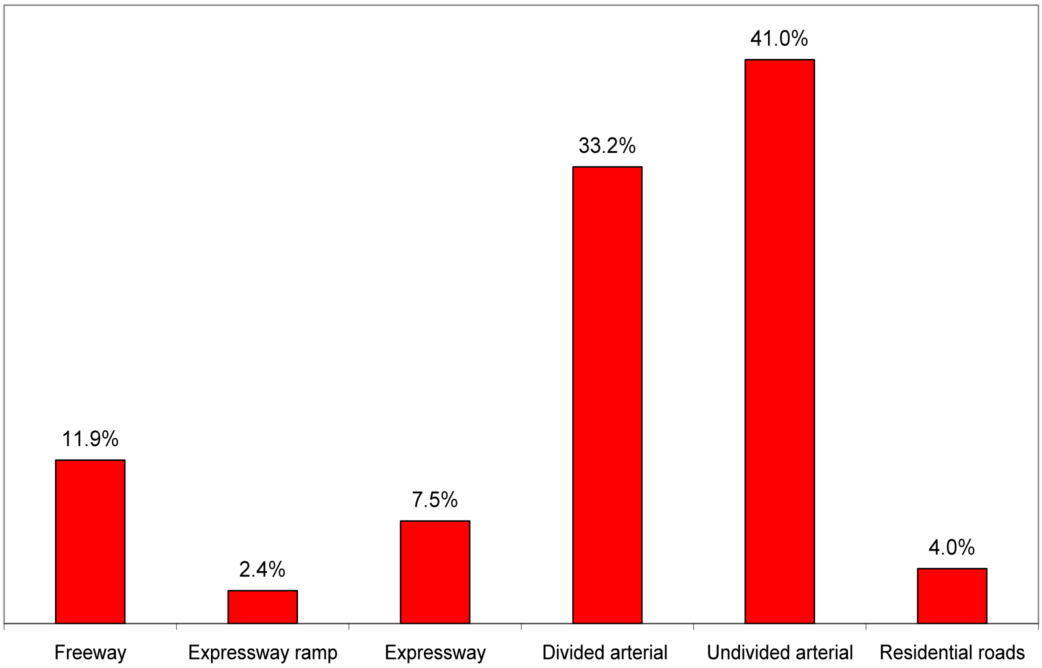

Figure 2. Distribution of fleet VKT by road type in the Perth airshed in 2006

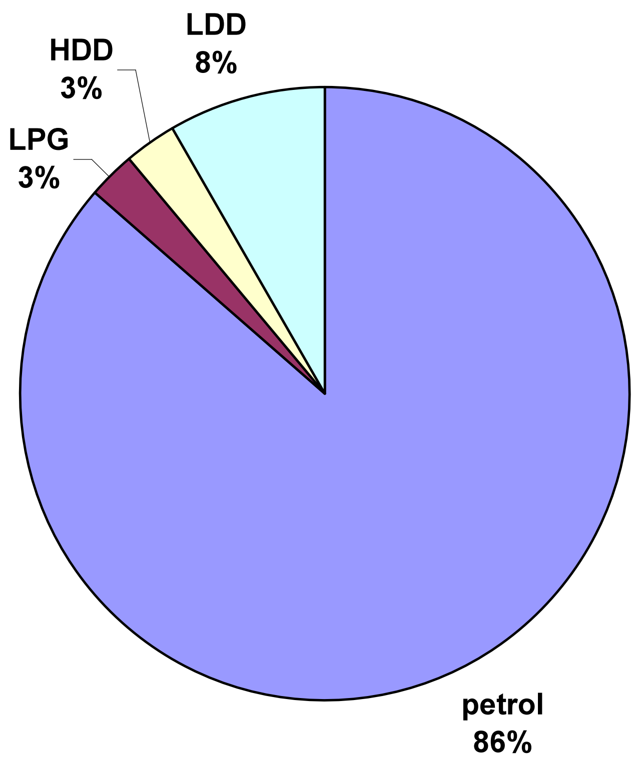

Figure 3. Vehicle Distribution Based on Fuel Type (ABS, 2007)
(LDD: light duty diesel, HDD: heavy duty diesel, LPG: liquefied petroleum gas)

2.3 Traffic volume variations

Hourly emission variations in an airshed are largely dependent on the hourly variations in behaviour of on-road vehicles, as different vehicle categories have different daily travel patterns. Passenger vehicles generally have dual peaks (morning and afternoon rush hours), while commercial vehicles mainly travel between business hours of the day. Hourly variations for all fleets in Perth for different road types are shown in Figure 4. These values are averaged for freeways, highways and arterial roads. The hourly profiles for vehicle activities provided by Main roads Australia contain total on-road vehicle volumes and do not differentiate between different vehicle categories. However, hourly profiles are necessary for accurate emissions estimation in advanced vehicle emission modelling.

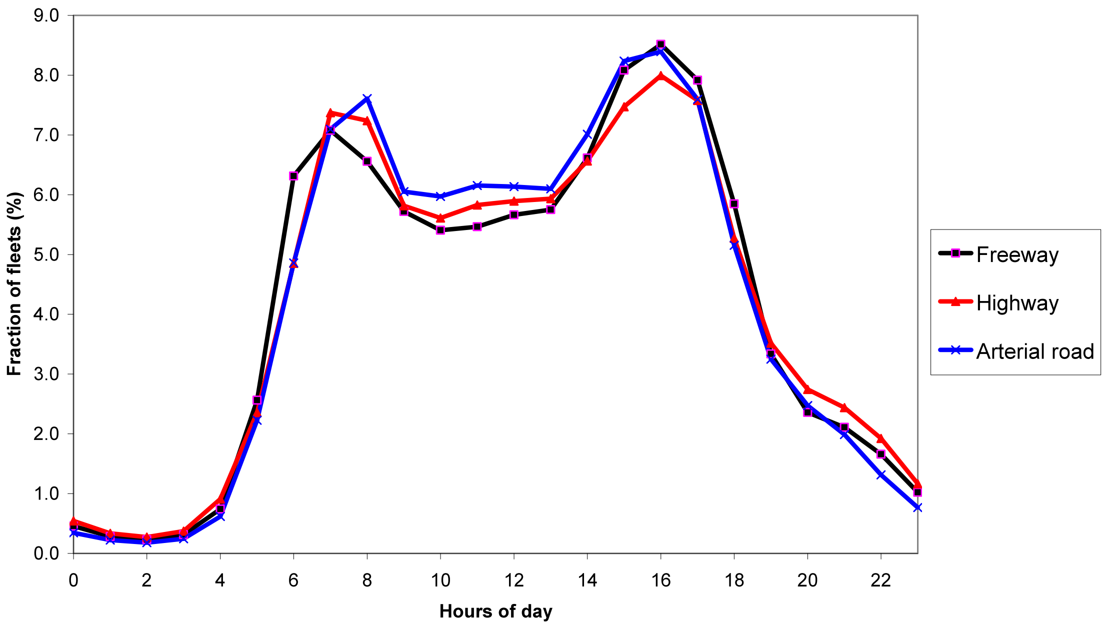

Figure 4: Average hourly variation of travel activity for all fleets in Perth in 2007

Temporal hourly variation data for all fleet categories (i.e. petrol passenger cars; diesel heavy duty commercial vehicles; diesel light duty vehicles; petrol light duty commercial vehicles; and motorcycles) were derived in the Perth airshed from travel activity data. The spectral mixture analysis technique was used to model hourly variations of travel activity in the Perth airshed (Rostampour and Yu, 2009). The average hourly variations in travel activities for all vehicle categories for the Perth region are presented in Appendix A (Figure A1).

In order to verify the model results, the modelled hourly profiles of travel activity were compared to the Perth vehicle emissions recorded in the Australian on-road remote sensing project (RSD) project (Bluett et al., 2008). The RSD project involved a program of roadside vehicle emissions measurements carried out in three Australian capital cities (Brisbane, Perth and Sydney) and included a video system to record freeze-frame images. All measurements in the RSD project were performed during half day surveys, either morning or afternoon. The average traffic volumes (out of 15,000 traffic counts) of these morning and afternoon surveys that were collected from arterial roads in Perth are shown in Appendix A (Figures A2-A5).

The patterns of hourly traffic variation for the modelled data and RSD project samples were found to be very similar. The differences in these patterns would most likely be due to road types included in these individual analyses. The RSD project collected vehicle emissions data from arterial and residential roads only, whereas the modelled data included all road types in the Perth airshed.

Emissions may also vary significantly with vehicle and engine operation, which in turn are strongly related to road types (selected on the basis of traffic flow conditions), and hence vehicle speeds and driving patterns. Driving condition adjustment factors were calculated for all fleets in the Perth airshed (Appendix B: Figures B1-B7).

2.4 Temporal variation

Temporal profiles (daily, weekly, and monthly) for on-road vehicle emissions in the Perth airshed were also constructed to estimate emissions for this study. Significant differences were observed between vehicle emissions on Saturdays, Sundays and weekdays (Figure 5). As a consequence of reduced traffic flow on Sundays, modelled emissions were noticeably lower on Sundays than weekdays. A seasonal difference in the distribution of vehicle-related emissions was also observed for weekdays as well as Saturdays and Sundays. Monthly profile of total exhaust VOC, CO and NOx emissions for fleets in Perth airshed were analysed for typical weekday and weekends. In addition, seasonal change in traffic counts and temperature may cause increased conversion of semi-volatile organic compounds into the gas phase during the summer months and/or effects of seasonal changes in fuel formulation. For this reason, seasonal and temperature adjustment factors need to be applied in vehicle emissions modelling.

The hourly variations in exhaust VOC, CO and NOx, emissions for the Perth fleet were also analysed (Appendix C: Figures C1-C4). Saturday and Sunday were found to have different hourly patterns from weekdays owing to changes in travel behaviours. There was a significant seasonal difference in the distribution of vehicle-related emissions as well as differences between vehicle emissions on Saturdays, Sundays and weekdays. As a consequence of reduced traffic on Sundays, emissions were noticeably lower on Sundays than weekdays.

Hourly emission variations in an airshed are largely dependent on the hourly variations in behaviour of on-road vehicles, as different vehicle categories have different daily travel patterns. One of the limitations in the traffic data used in this study was the lack of sufficient detail on traffic types in the Perth airshed. The hourly profiles for vehicle activities in the traffic dataset did not differentiate between different vehicle categories. A new method, which facilitates the spectral mixture analysis, was used to extract hourly traffic profiles for different vehicles from readily available traffic data.

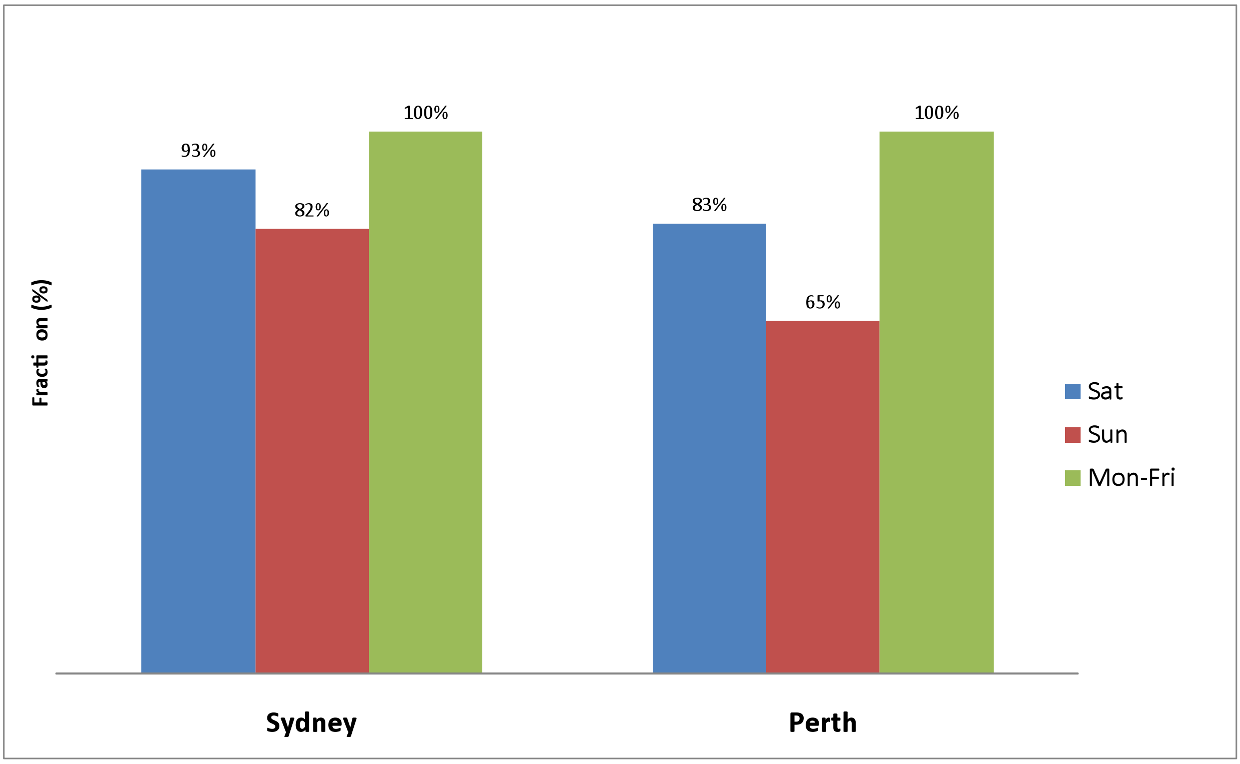

Figure 5: Comparison of weekday and weekend traffic factors for Sydney and Perth airsheds (2006–2007)

2.5 Emission factors

The emission factors in this study were based on those contained in the DECC NSW Technical Report (DECC NSW 2007) and James (1995). The base emission factors of petrol passenger cars currently used for the inventory, which represent the latest and best available data under Australian conditions, are derived from a large data pool involving over 8,000 emission testing records. This data pool originated from a number of government and industry laboratories and included late 1970s to early 1990s vehicle models in Australia (Xu 2000).

A different dataset was used to develop diesel vehicle emission factors. Emission deterioration was not taken into account in this dataset as heavy duty vehicles have significantly less emissions deterioration than passenger cars due to the greater robustness of the diesel engines (DECC NSW 2007). Particulate emissions from petrol vehicles are not regulated by current emission standards and are believed to be much lower than those from diesel vehicles on a per vehicle basis. Given the dominant proportion of petrol passenger cars in most urban motor vehicle fleets, contributions from petrol vehicles to the fleet-wide particulate emissions may become more significant as diesel particulate emissions are reduced by tightening emission standards.

Where emission factors were not available (e.g. for a particular period), the default factors were derived using the National Pollutant Inventory (NPI) Emissions Estimation Techniques (EET) Manual for Mining (NPI 2001).The averaged base emission factors estimated for petrol and diesel passenger cars, diesel light commercial vehicles, heavy-duty trucks, diesel buses, and motorcycles are shown in Appendix D.

The proportion of on-road diesel heavy-duty commercial vehicles (3%) is much smaller than that of petrol passenger cars (74%), but their contributions are significant in the total on-road PM and NOx emissions. As heavy-duty diesel vehicles in Australia are mainly imported, international emission data on these vehicles are more applicable than earlier estimates used in the Australian inventory. The dataset used in this study contained a range of overseas emission data which have been used to develop the base emission factors of diesel rigid trucks (DECC NSW, 2007).

The diesel light-duty category includes diesel passenger cars and diesel light-duty commercial vehicles. This category of cars is not a big component of the Perth fleet (3.2% of total fleet) but does have significantly distinctive emission characteristics.

Petrol light-duty commercial vehicles have been the most rapidly growing component of the urban fleet in recent years. In addition, there are an increasing number of light duty commercial vehicles using LPG. In this study, LPG-fuelled vehicles were not treated as a separate category and were grouped in the Petrol Light Duty Commercial Vehicles category. Emission factors for LPG in the EET Manual were applied to this group. The deterioration rates were assumed to be the same as those for non-catalyst cars (DECC NSW, 2007).

Other vehicles in this inventory include motorcycles, campervan, vans and recreational vehicles. Emissions data for these vehicle categories are inadequate and also their proportion of the on-road kilometres travelling for them is small compared to other groups. Therefore, for the purposes of this study, these vehicle types were grouped into a single category. The motorcycles emission factors used in this study were extracted by DECC NSW from the European Emission Inventory Guide Book (DECC NSW, 2007). Emission data for recreational vehicles were adopted from USEPA emission data. The emission factors that were applied to campervans were derived using a VKT-based model (DECC NSW, 2007).

2.6 Deterioration rates

The emission control technologies used for vehicles of different age ranges can have significant impacts on the estimation of vehicle emissions. The original emission quality and subsequent emission deterioration with time are simulated by the use of deterioration factors based on the average distance travelled by vehicles of different ages (NPI 2000) and deterioration factors have been developed from Australian test data used for ADR27A. Table 1 lists the average emission deterioration rates for NO_x, VOC and CO that were developed using the CVS-C test procedure as specified in ADR27A.

The Australian diesel emission test dataset is not sufficiently large enough to establish satisfactory emission deterioration profiles for the different types of diesel vehicles. The limited data suggests that the magnitude of emission deterioration for heavy-duty diesel vehicles and diesel light-duty vehicles is much less significant than that of passenger cars (DECC NSW, 2007). Therefore, in this study, the deterioration rates for diesel vehicles were excluded in the modelling and the base emission factors for diesel vehicles were average emission factors over the vehicles useful lifetime.

Table 1. The average base emission deterioration rates of NO_x, VOCs and CO

Model year	Deterioration rate (g/km/km)		
	NO_x	VOCs	CO
1976-1985	7.0×10^{-6}	9.0×10^{-6}	1.15×10^{-4}
1986-1990	1.47×10^{-5}	5.38×10^{-6}	9.46×10^{-5}
1991-1995	1.08×10^{-5}	2.91×10^{-6}	6.2×10^{-5}
1996-2000	8.85×10^{-6}	1.68×10^{-6}	3.73×10^{-5}
2001-2031	8.10×10^{-6}	1.40×10^{-6}	2.80×10^{-5}

2.7 Evaporative fuel emissions

There are different sources of evaporative (non-exhaust) emissions based on vehicle operating situations such as diurnal, hot soak, running losses, resting losses, refuelling losses and crankcase emissions. Diurnal breathing losses occur as the fuel tank heats up during the day. Resting losses result from vapour permeation and liquid leaks through various parts of the evaporative control system. Hot Soak losses occur after the vehicle has been turned off and result from evaporation of fuel in the engine and fuel delivery system. Running evaporative losses occur as the vehicle is being operated over the road. Refuelling losses are a result of vapour space displacement and spillage. Crankcase losses are primarily the result of defective PCV (Positive Crankcase Ventilation) systems.

Evaporative emissions (except running losses) occur when vehicles are stationary, thus they are not directly VKT-related. In order to quantify diurnal and hot soak losses, some additional vehicular trip data are required including: the number of trip starts, number of trip ends and trip duration information. This information is not currently available for this emission inventory. Therefore, a VKT-based approach, similar to the NSW Metropolitan Air Quality Study inventory, was used to estimate evaporative emission (DECC NSW, 2007). The VOCs evaporative losses estimates in this study matched those in the Sydney Metropolitan Air Quality Study.

Separate daily temporal profiles were derived for evaporative emissions, as evaporative emissions are significantly affected by the hourly change of ambient temperature. The magnitude of evaporative emissions under different scenarios such as winter, summer and high-oxidant scenarios were also estimated. The evaporative emissions weightings were calculated by determining the average temperature during the year, and comparing this value to averages for winter, summer and high-oxidant scenarios. The fractional contribution from each of these was incremented in proportion. Results demonstrate the relationship between temperature and evaporative VOCs (Figure 6). Significant differences were observed between vehicle emissions on typical summer days, winter days and high-oxidant days.

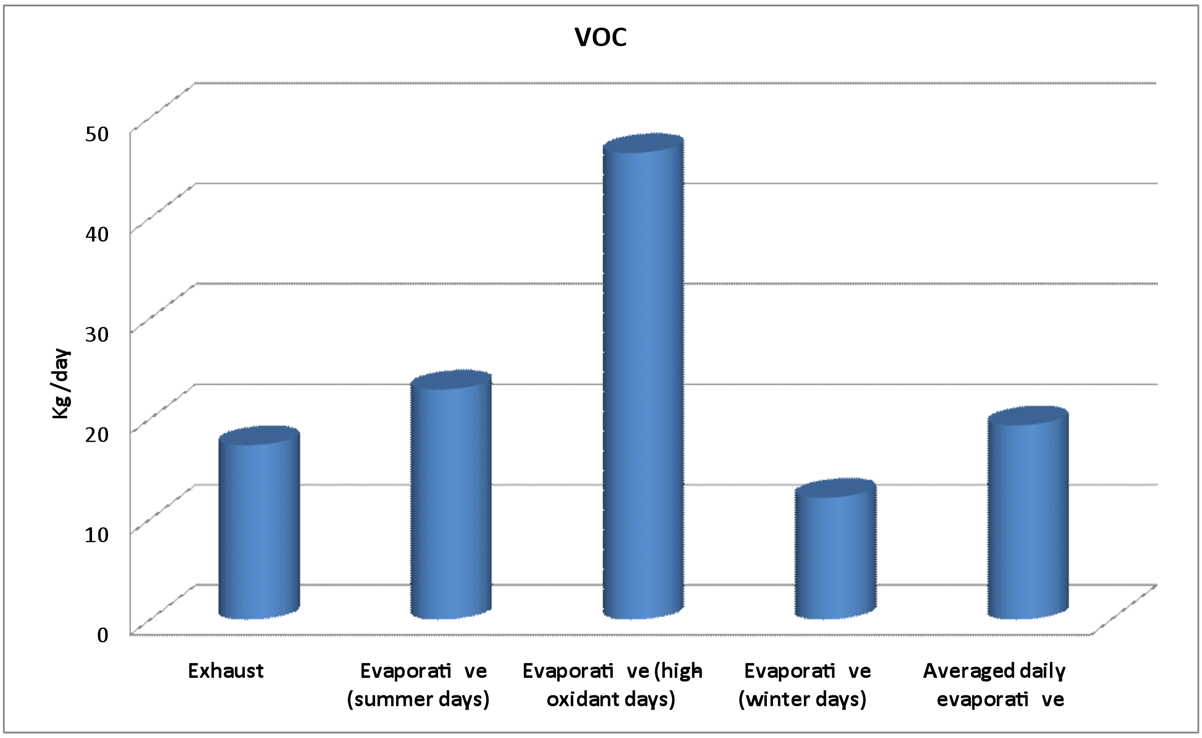

Figure 6: Exhaust and evaporative VOC emissions (kg/day) for typical summer, winter and high-oxidant days (2006-2007)

The evaporative emissions weightings were calculated by determining the average temperature for each day, and comparing this value to averages for winter, summer and high-oxidant scenarios (13°C, 21.5°C and 27°C). The fractional contribution from each of these was incremented in proportion. A day with an average temperature of 13°C or less added one to the sum for the winter day scenario, one with an average of 21.5°C added one to that for the summer day scenario, and one with an average of 27°C or more added one to the sum for the high oxidant day scenario.

2.8 Calculation of final emissions

Emissions of the substances cited in the National Pollutant Inventory Guide (NPI 2000), were estimated using a range of techniques using in-house processing software. The first set of profiles used by this software contained the principal emissions relating to photochemical smog, namely, NOx, CO and VOCs. The second set contained evaporative VOC emissions for nominal summer, winter and high oxidant days. A VKT-based approach was used to estimate evaporative emissions, assumed to be only from petrol vehicles and treated as a separate category. The third set of profiles contained estimates for sulphur dioxide and PM_{10}. These files included ratios for a set of road types (freeway, arterial road, residential road, congested road). The use of ratios to the standard rate allows for planned future improvements, in which traffic speed and congestion estimates, rather than road classes, can be used to correct for road conditions.

3 Estimated emissions

Total estimated annual emissions of CO, NOx, VOC, SO_2 and PM_{10} from all vehicular categories for the Perth airshed for both 2001/2002 and 2006/2007 are shown in Table 2. Emission factors and VKT are two key parameters required to estimate vehicle emissions. Motor vehicle emissions are estimated from data on spatial VKT by road type and fleet composition, and the relevant emission factors (NPI 2001). Therefore, any increase and decrease in VKT and vehicle emission factors are directly reflected in the vehicle emission estimations.

Total VKT on Perth roads increased by 18 per cent between 2001 and 2007 (Main Roads WA, 2008). This increase in VKT may be due to several factors including population growth, vehicle fleet growth and more individual travel. These three factors have combined to steadily increase total VKT in Perth in recent years. On the other hand, emission factors used to estimate vehicle emissions, in general, tend to decrease for newer vehicles due to improvement in emissions performance of newer vehicles.

A decrease in annual emissions of CO and VOC was found in this study, notwithstanding the increasing VKT during this period. Emissions of NOx, SO_2 and PM_{10} increased over this period. The reduction in VOC and CO emissions and the increase in NOx emissions is likely due to newer engine design, where air and combustion temperature increases lead to reduced VOC and CO formation, but increased NOX formation (Reitze 2001). Nevertheless, it should be emphasised that the relationship between VOC, CO and NOx formation is very complex.

It must be noted that more precise estimation of PM_{10} and SO_2 emissions needs to be carried out due to some limitations in the current vehicle emission inventory model and also lack of complete emission information about these pollutants.

This study also examined the magnitude of evaporative emissions under different scenarios such as winter, summer and high-oxidant scenarios. The weighted evaporative emissions, which are calculated from different scenarios, are illustrated in Table 3 for both 2001/2002 and 2006/2007. The estimated annual VOC emissions of 13,400 tonnes arise almost entirely from petrol fuelled vehicles. Evaporative loss emissions account for 53 percent of total VOC emissions. Total VOC emissions decrease by about 17 per cent between 2001 and 2007, while exhaust VOC emission reduction is approximately 8 per cent over this period.The decrease of VOC emissions would be the result of the uptake of the strictest emissions limits (ADR37/01) by a large proportion of petrol fuelled passenger car fleet and increased control efficiency of evaporative emissions (ADR79/00, ADR79/01).

Speciation of total VOCs emissions was calculated from total estimated VOC emissions. The speciation factors have been adopted from the DECC NSW Technical Report (DECC NSW 2007). Table 19 presents total estimated annual emissions for speciation of VOC (selected substances) from on-road mobile sources in the Perth airshed.

Table 2. Annual total emissions of principal pollutants (tonnes/year) from vehicles in the Perth airshed for 2001/2002 and 2006/2007

	2006/2007	2001/2002
Oxides of nitrogen (NO_x)	16,302	15,390
Carbon Monoxide (CO)	100,285	111,484
Sulfur dioxide (SO_2)	191	164
Particulate matter (PM_{10})	335	287
Total volatile organic compounds (VOCs)	13,404	16,097

Table 3. Exhaust and evaporative VOC emissions (tonne/year) for 2001/2002 and 2006/2007

	2006/2007	2001/2002
Exhaust VOCs	6,341	6,880
Evaporative VOCs (weighted annual estimation)	7,063	9,218
Total VOCs	13,404	16,097

Table 4. Selected VOC speciation of motor vehicle emissions (tonne/year) for 2001/2002 and 2006 / 2007

	2006/2007	2001/2002
1,3 butadiene	53	64
Acetaldehyde	164	197
Benzene	490	588
Formaldehyde	190	228
Isomers of xylene	716	860
Polycyclic aromatic hydrocarbons	46	56
Sulfur dioxide	335	402
Toluene	508	610

Separate daily temporal profiles were also derived for evaporative emissions, as evaporative emissions are significantly affected by the hourly change of ambient temperature. The magnitude of evaporative emissions under different scenarios such as winter, summer and high-oxidant scenarios were also estimated (Figures 7-8). There were significant differences between vehicle emissions in typical summer, winter and high-oxidant scenarios.

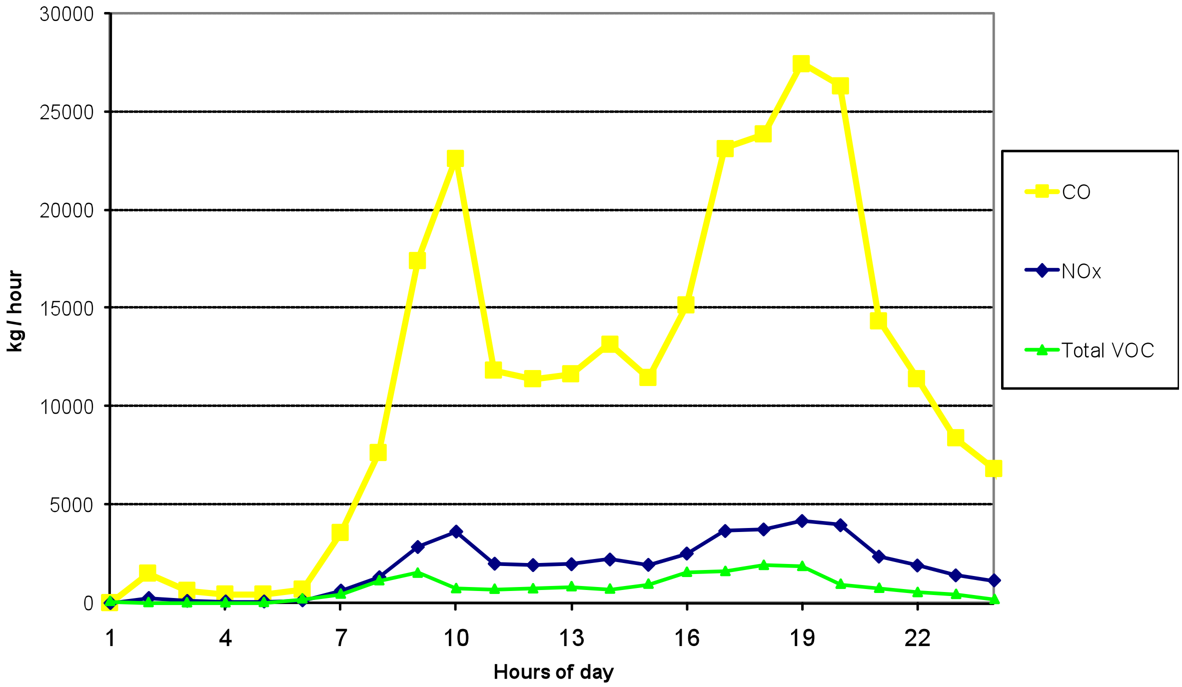

Figure 7: Average hourly variations in vehicular emissions in the Perth airshed (2006-2007)

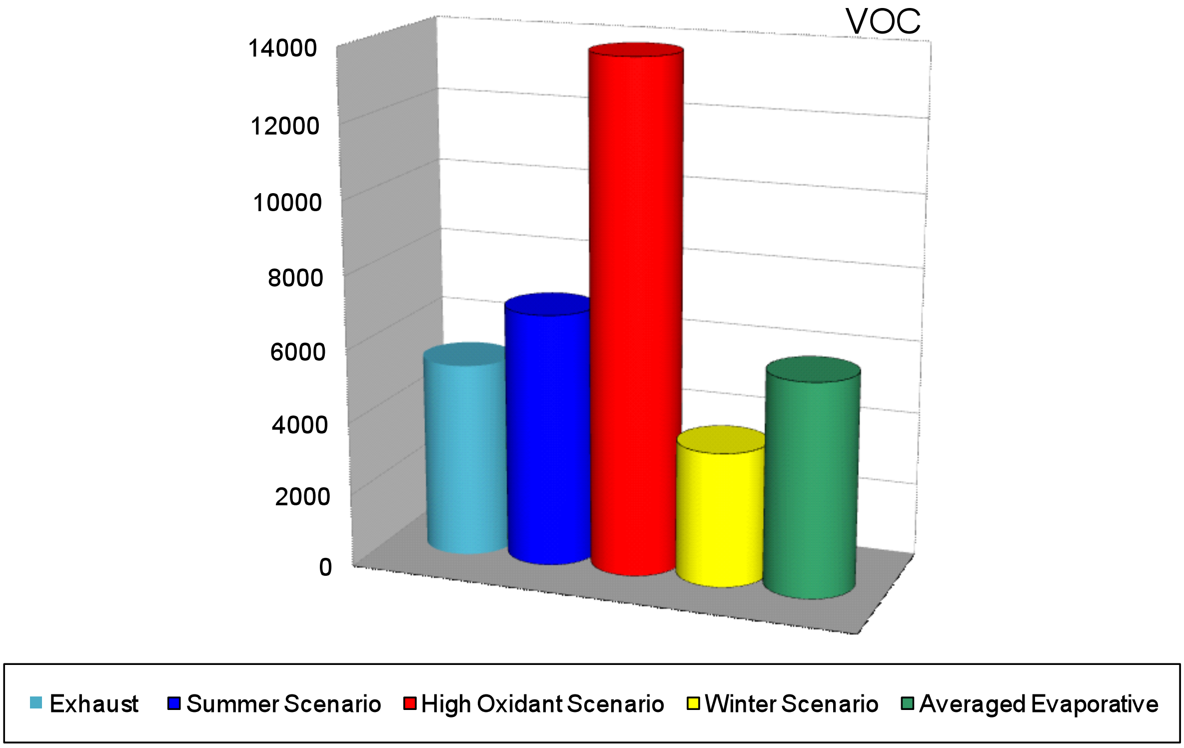

Figure 8: Exhaust and evaporative VOC emissions (tonnes / year) for summer, winter and high-oxidant scenarios (2006-2007)

4 Conclusion

Accurate estimation of on-road vehicle emissions is important for policy-making and effective control measures. In order to estimate roadway emissions, detailed information is required such as: emission factors for different vehicles, vehicle class distribution, driving cycles, driving behavior and traffic data. Detailed traffic data play a significant role in estimating vehicle emissions.

Temporally accurate and up-to-date traffic data on road networks are important for numerous reasons including vehicle emission inventories. However, these types of databases are not available for the Perth road network. Traffic data collection and analysis is very expensive and requires deploying traffic sensors around the road network to collect traffic information network-wide. This can be a big challenge as a road network grows.

More traffic data will be required for each vehicle category in the Perth road network to allow further comparison between modeled data and real-world traffic data. The pattern of hourly traffic variations for the modelled and real-world samples are comparable with small differences, which are expected because the modeled data were generated for all road types (freeways, highways, arterial roads and residential roads), while real-world data were mainly collected from residential areas. The use of spectral mixture analysis method as in this study is one means by which hourly profiles may be extracted from traffic data.

The findings of this study can be used as an effective tool to generate projections for different pollutants, and to inform air quality policy and the design and delivery of vehicle emissions reduction programs. The output is also useful in the assessment of transport choices and improved public transport, as well as optimising behavioural change programs to reduce vehicle emissions. Vehicle emissions reduction may be best achieved by targeted behavioural change programs in relation to transport choices as well as improved public transport. Vehicle emissions modelling can be an effective tool in informing air quality policy and provide a means of estimating community exposure to vehicle-related air pollutants and of evaluating the effectiveness of air quality policies aimed at reducing vehicle emissions.

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Appendix A: Traffic volume variations

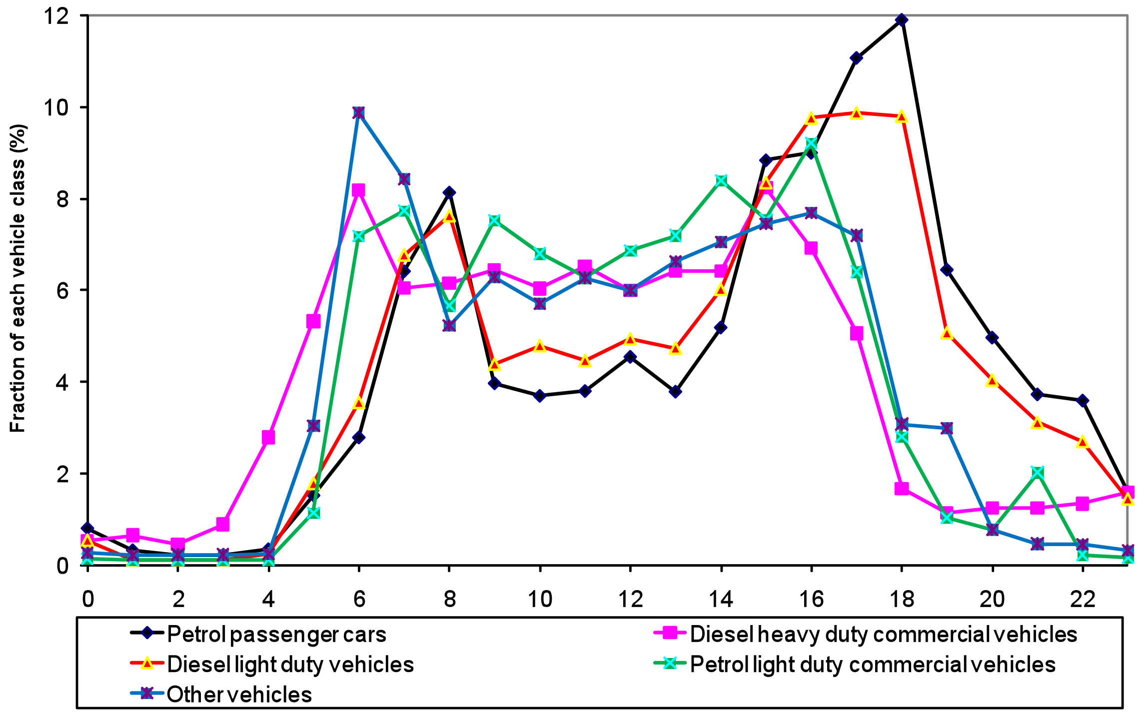

Figure A1: Modelled hourly variation in travel activity in freeways for all fleets

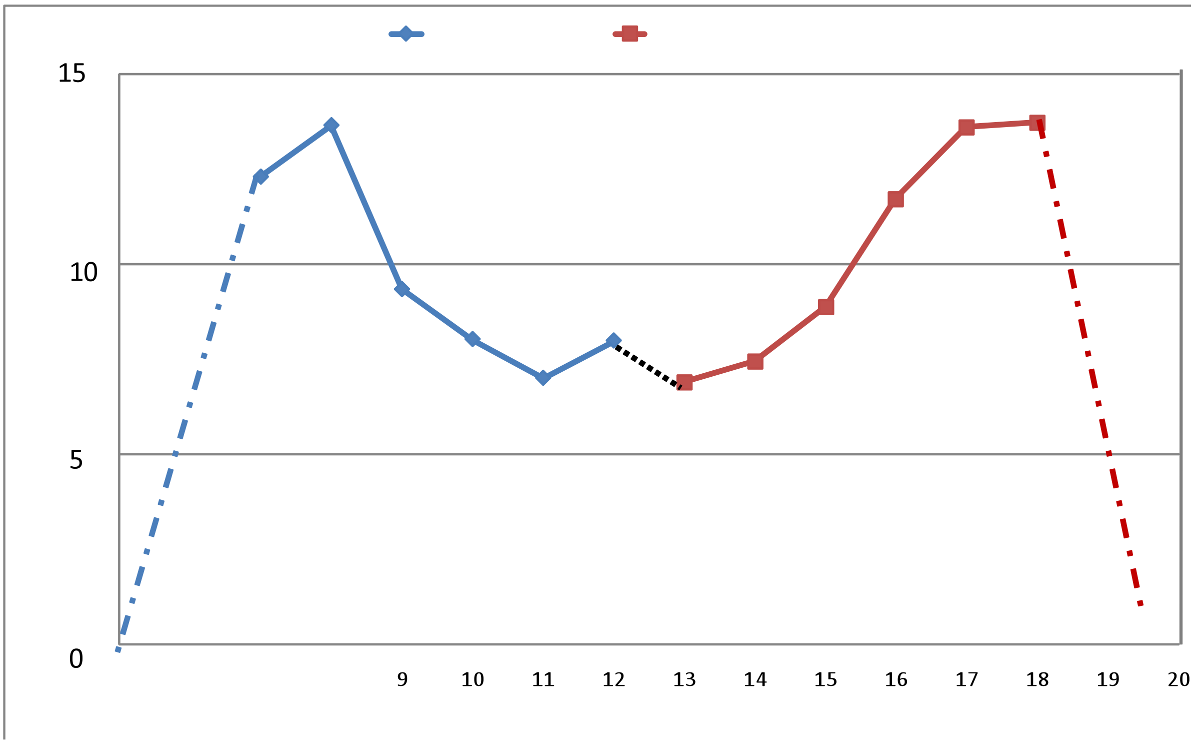

Figure A2: Average hourly variations in travel activity for passenger vehicles in Perth based on real-world traffic data

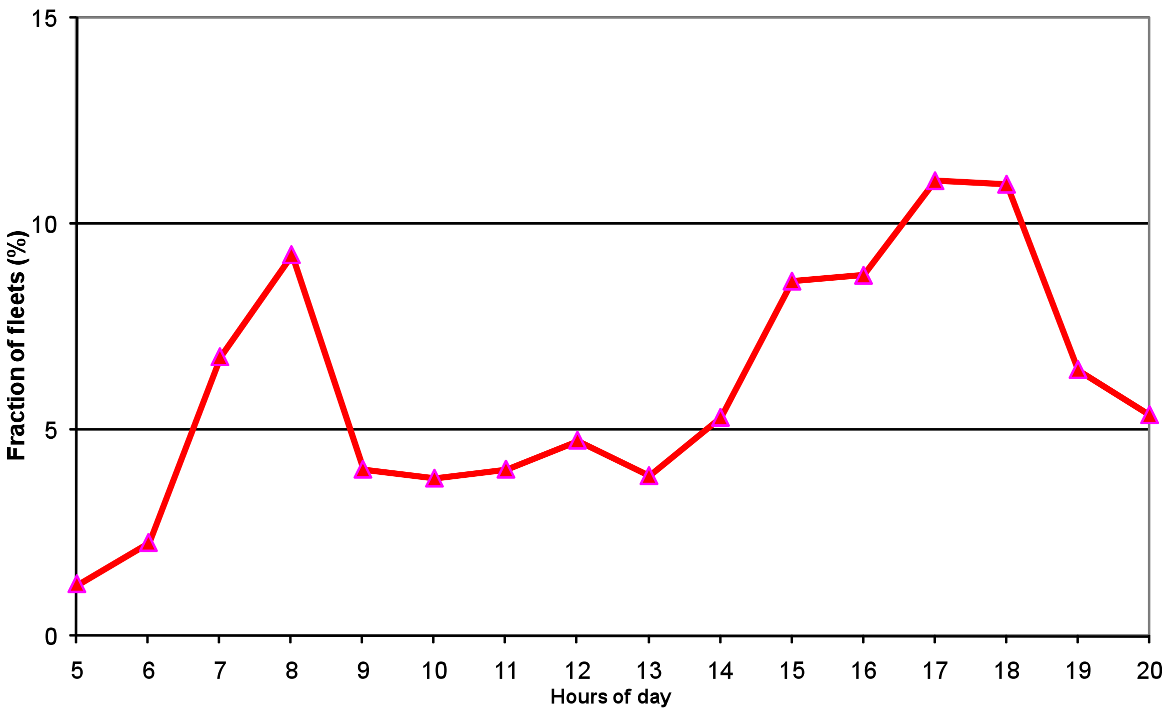

Figure A3: Average hourly variations in travel activity for passenger vehicles in Perth based on modelled data

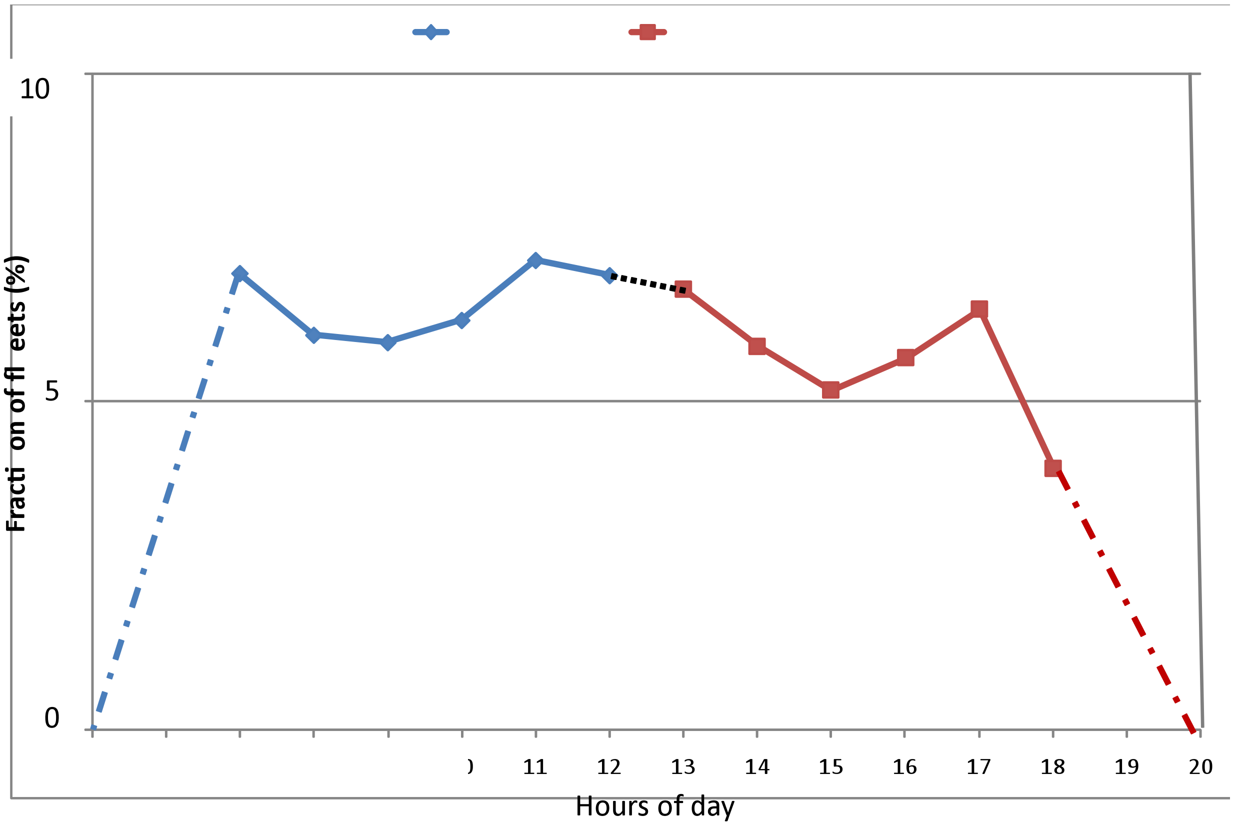

Figure A4: Average hourly variations in travel activity for diesel commercial vehicles in the Perth airshed based on real-world traffic data

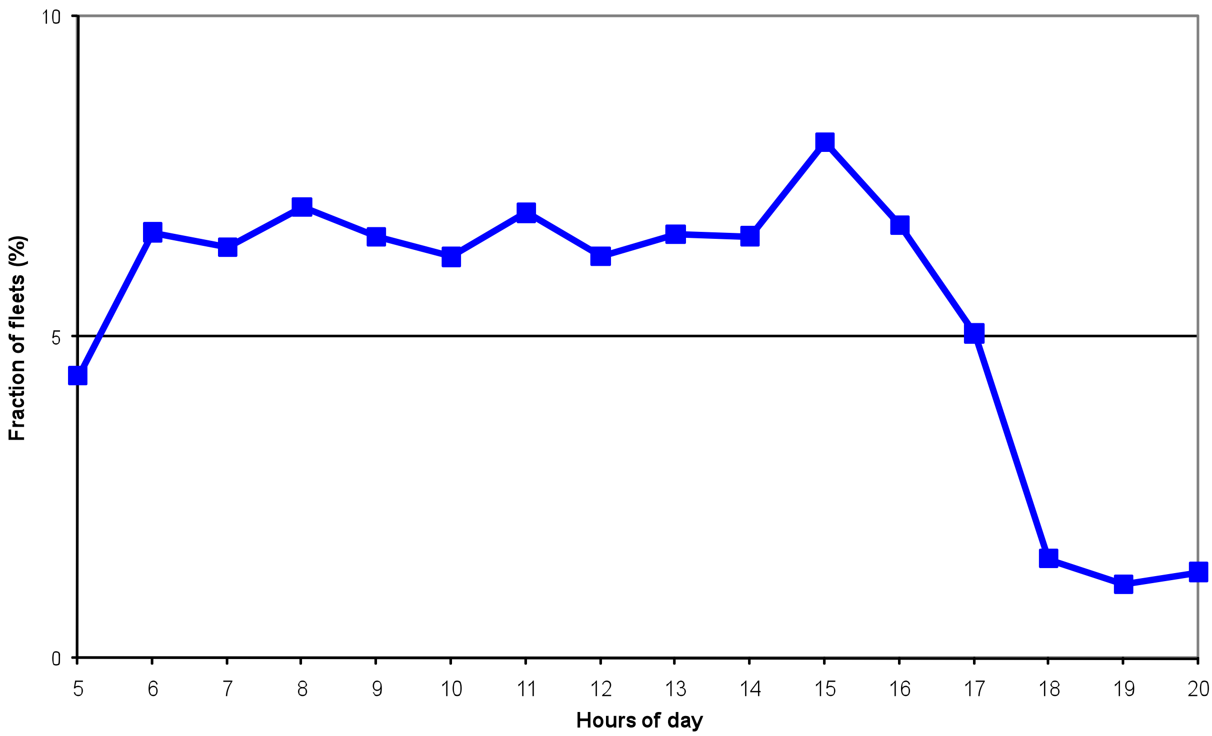

Figure A5: Average hourly variations in travel activity for diesel commercial vehicles in the Perth airshed based on modelled data

Appendix B: Driving conditions modification factors

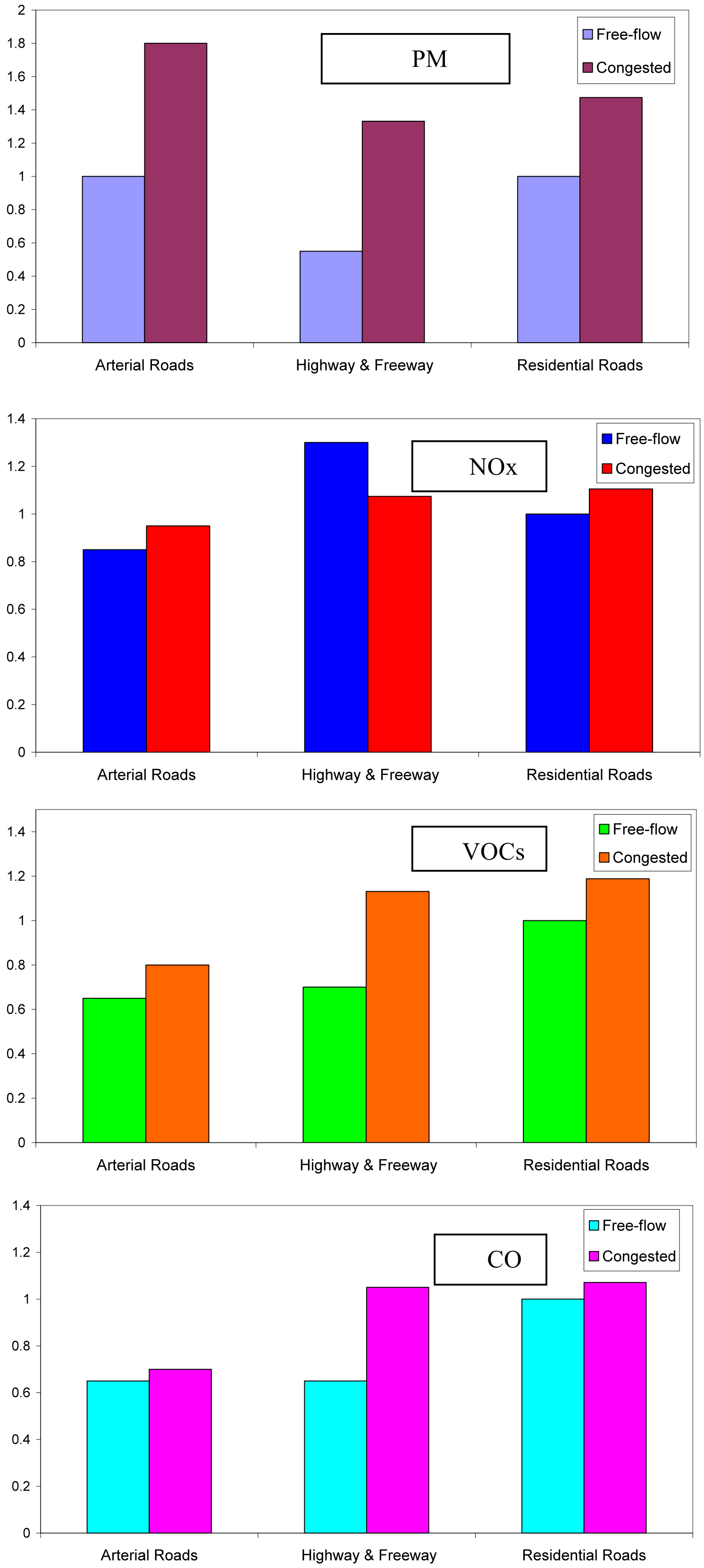

Figure B1: Driving condition modification factors for petrol passenger cars (PM, NOx, VOCs and CO)

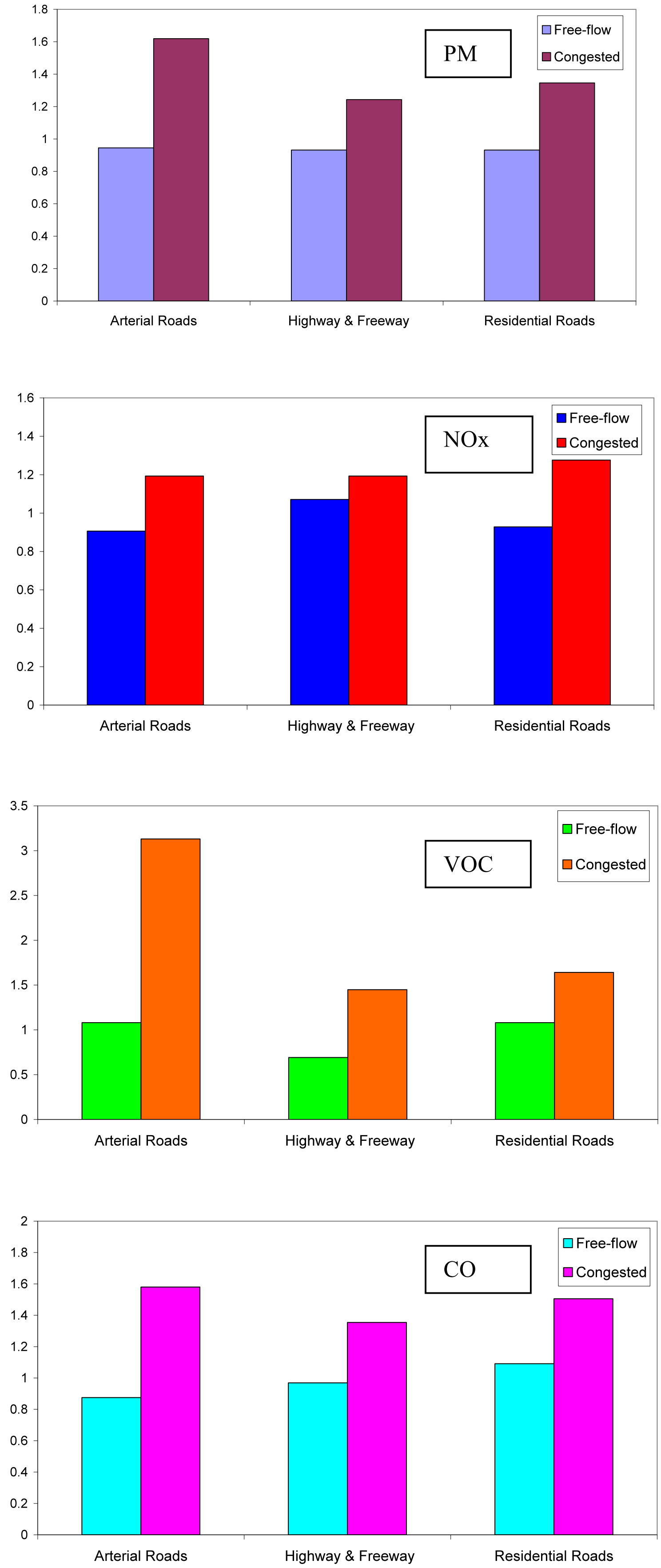

Figure B2: Driving condition modification factors for diesel articulated trucks (PM, NOx, VOCs and CO)

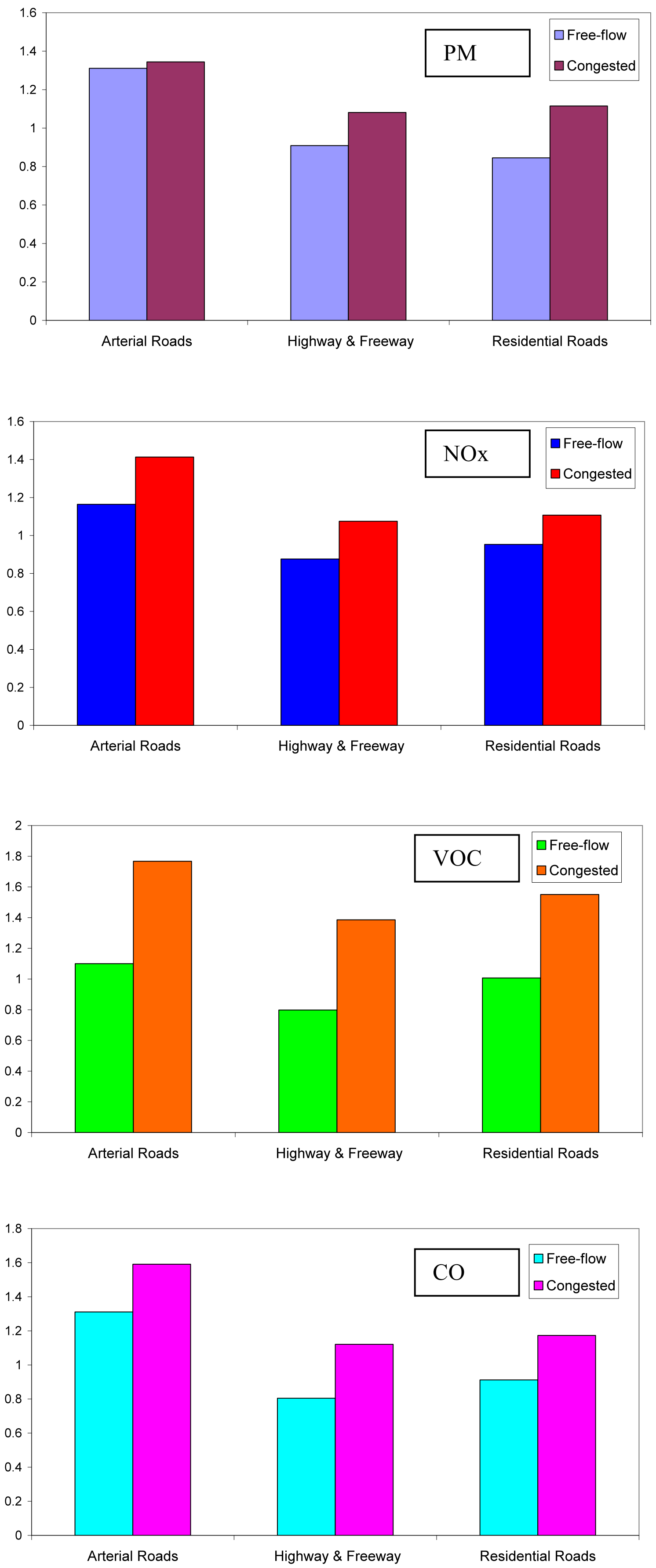

Figure B3: Driving condition modification factors for diesel buses (PM, NOx, VOCs and CO)

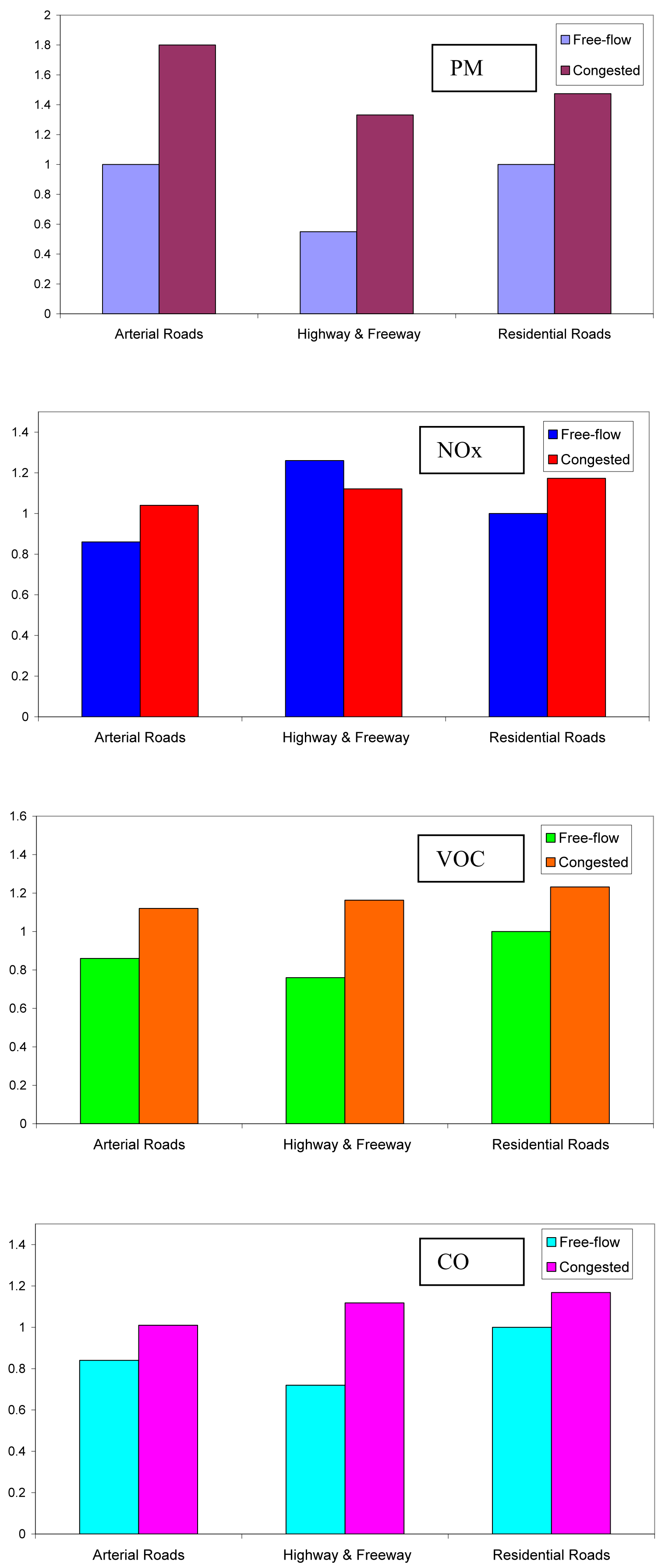

Figure B4: Driving condition modification factors for petrol light duty commercial vehicles (PM, NOx, VOCs and CO)

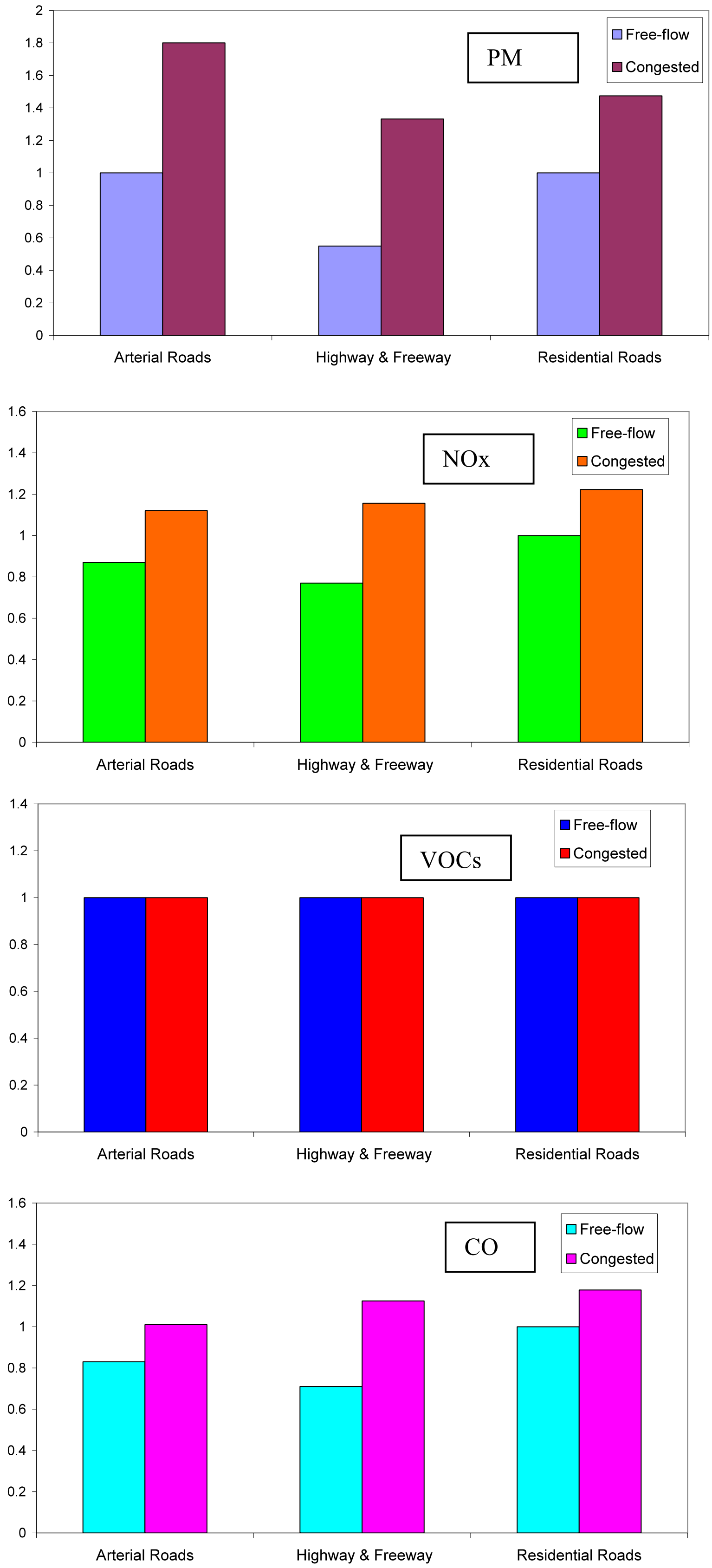

Figure B5: Driving condition modification factors for other vehicles (PM, NOx, VOCs and CO)

Appendix C: Temporal variations

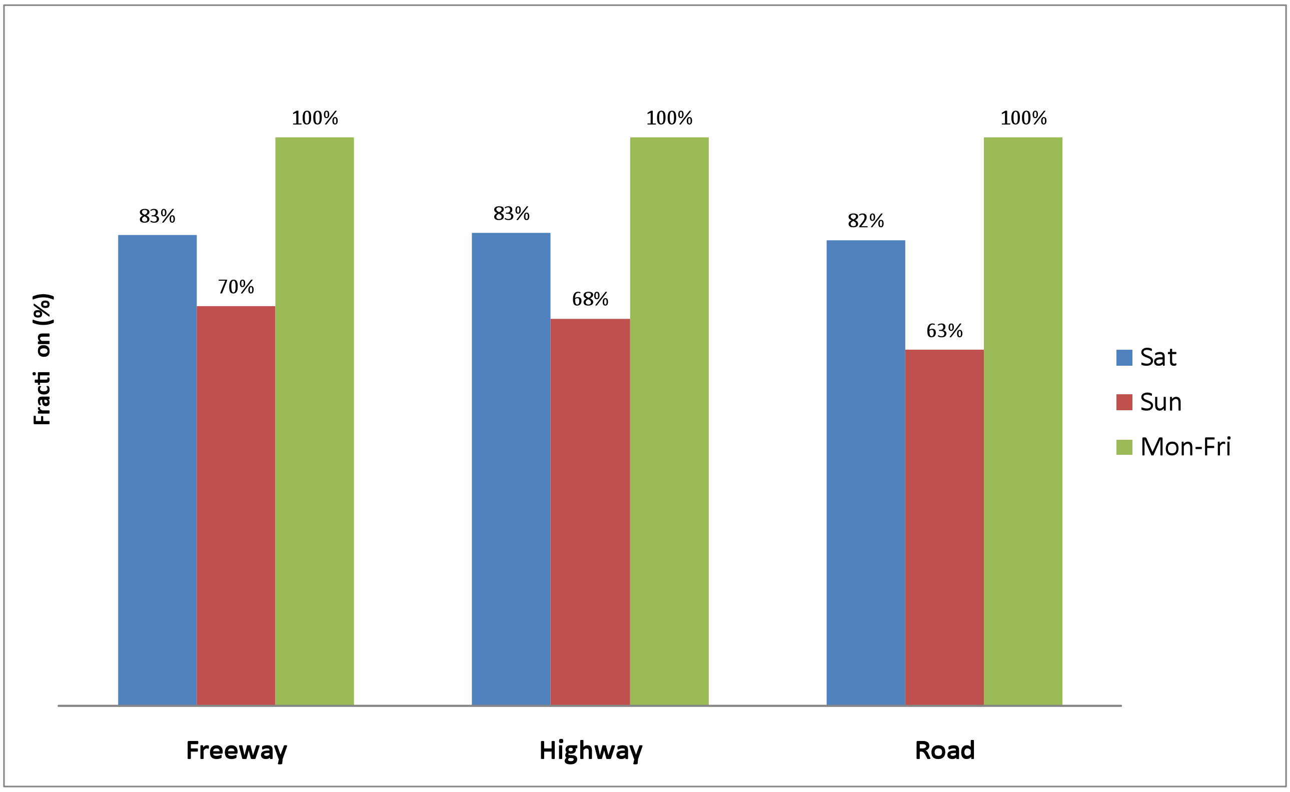

Figure C1: Weekday and weekend traffic factors for different road types in Perth (2006-2007)

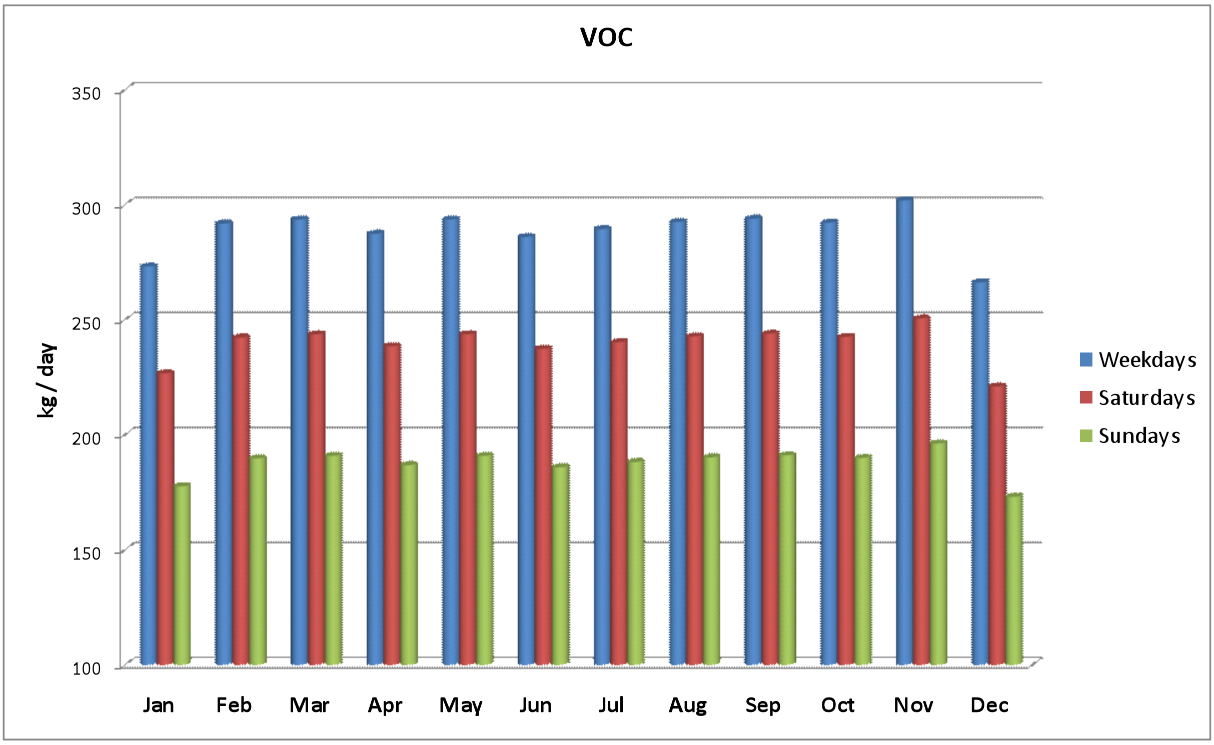

Figure C2: Monthly profile of total estimated exhaust VOC emissions (kg/day) from Perth fleets for typical weekday and weekends (2006-2007)

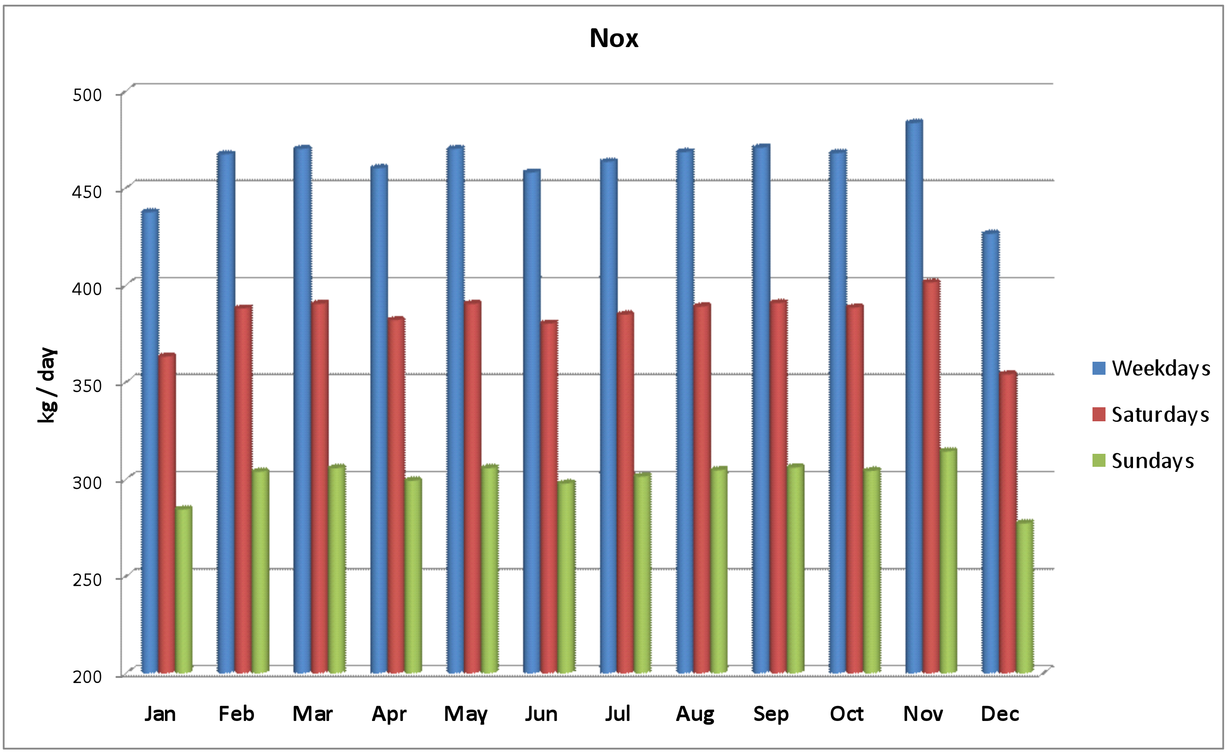

Figure C3: Monthly profile of total estimated NOx emissions (kg/day) from Perth fleets for typical weekday and weekends (2006-2007)

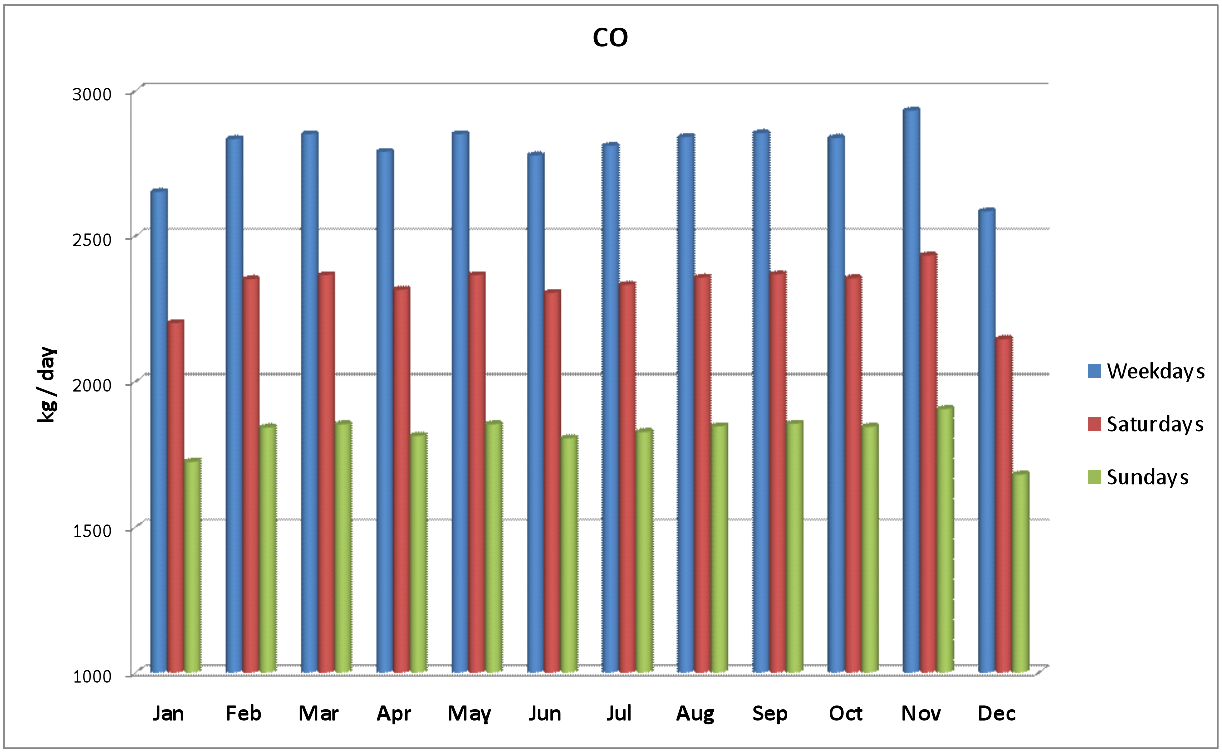

Figure C4: Monthly profile of total estimated CO emissions (kg/day) from Perth fleets for typical weekday and weekends (2006-2007)

Appendix D: Average base emission factors

Table D1: Average Base Emission Factors for VOCs, NOx, CO, SO_2, Pb and PM_{10} from Petrol Passenger Vehicle Exhaust (kg/km)

	VOCs	NO_x	CO	SO_2	Pb	PM_{10}
1981-1985	0.345	0.795	5.076	0.0215	0.004	0.08
1986-1990	0.348	0.729	4.833	0.0213	0.000322	0.05
1991-1995	0.3315	0.547	4.068	0.0210	0.00021	0.03
1996-2000	0.29	0.31	2.77	0.0208	0.00021	0.03
2001-2005	0.25	0.15	1.6	0.0207	0.00011	0.02

Table D2: Average Base Emission Factors for VOCs, NOx, CO, SO_2, Pb and PM_{10} from Diesel Heavy Truck Exhaust (kg/km)

	VOCs	NO_x	CO	SO_2	Pb	PM_{10}
1981-1985	1.721	16.971	8.781	0.0325	0.00081	0.62
1986-1990	1.192	16.332	6.910	0.0323	0.00069	0.53
1991-1995	0.943	15.685	4.975	0.0321	0.00053	0.41
1996-2000	0.779	11.8	3.603	0.0319	0.00052	0.4
2001-2005	0.482	9.988	2.126	0.0317	0.00049	0.38

Table D3: Average Base Emission Factors for VOCs, NOx, CO, SO_2, Pb and PM_{10} from Diesel Bus Exhaust (kg/km)

	VOCs	NO_x	CO	SO_2	Pb	PM_{10}
1981-1985	1.37	15.11	7.49	0.7085	0.00081	0.46
1986-1990	1.28	14.35	6.70	0.7083	0.00117	0.42
1991-1995	1.15	12.92	4.79	0.7081	0.00109	0.39
1996-2000	0.998	10.70	2.74	0.7080	0.00084	0.3
2001-2005	0.971	9.34	2.31	0.7078	0.00078	0.28

Table D4: Average Base Emission Factors for VOCs, NOx, CO, SO_2, Pb and PM_{10} from Diesel Light Commercial Vehicle Exhaust (kg/km)

	VOCs	NO_x	CO	SO_2	Pb	PM_{10}
1981-1985	1.483	8.844	5.921	0.0095	0.000845	0.65
1986-1990	1.361	7.169	5.425	0.0093	0.00078	0.6
1991-1995	1.198	6.178	3.767	0.0090	0.000715	0.55
1996-2000	1.113	5.452	2.165	0.0089	0.000429	0.33
2001-2005	1.011	4.487	1.172	0.0087	0.000325	0.25

Table D5: Average Base Emission Factors for VOCs, NOx, CO, SO_2, Pb and PM_{10} from Diesel Passenger Vehicle Exhaust (kg/km)

	VOCs	NO_x	CO	SO_2	Pb	PM_{10}
1981-1985	1.483	1.618	3.9	0.0095	0.000845	0.65
1986-1990	1.361	1.514	3.3	0.0093	0.00078	0.6
1991-1995	1.198	1.428	2.4	0.0090	0.000715	0.55
1996-2000	1.113	1.275	1.331	0.0089	0.000429	0.33
2001-2005	1.011	1.65	1.172	0.0087	0.000325	0.25

Table D6: Average Base Emission Factors for VOCs, NOx, CO, SO_2, Pb and PM_{10} from Petrol Light Commercial Vehicle Exhaust (kg/km)

	VOCs	NO_x	CO	SO_2	Pb	PM_{10}
1981-1985	0.345	0.795	5.076	0.024	0.004	0.08
1986-1990	0.348	0.729	4.833	0.024	0.000322	0.05
1991-1995	0.3315	0.547	4.068	0.024	0.00021	0.03
1996-2000	0.29	0.31	2.77	0.024	0.00021	0.03
2001-2005	0.25	0.15	1.6	0.024	0.00011	0.02

Table D7: Average Base Emission Factors for VOCs, NOx, CO, SO_2, Pb and PM_{10} from Motorcycle Exhaust (kg/km)

	VOCs	NO_x	CO	SO_2	Pb	PM_{10}
1981-1985	6.075	0.0215	10.4	0.012	0.00011	0.01
1986-1990	6.073	0.0215	10.4	0.012	0.00011	0.01
1991-1995	6.071	0.0215	10.4	0.012	0.00011	0.01
1996-2000	6.069	0.0215	10.4	0.012	0.00011	0.01
2001-2005	6.067	0.021	10.4	0.012	0.00011	0.01